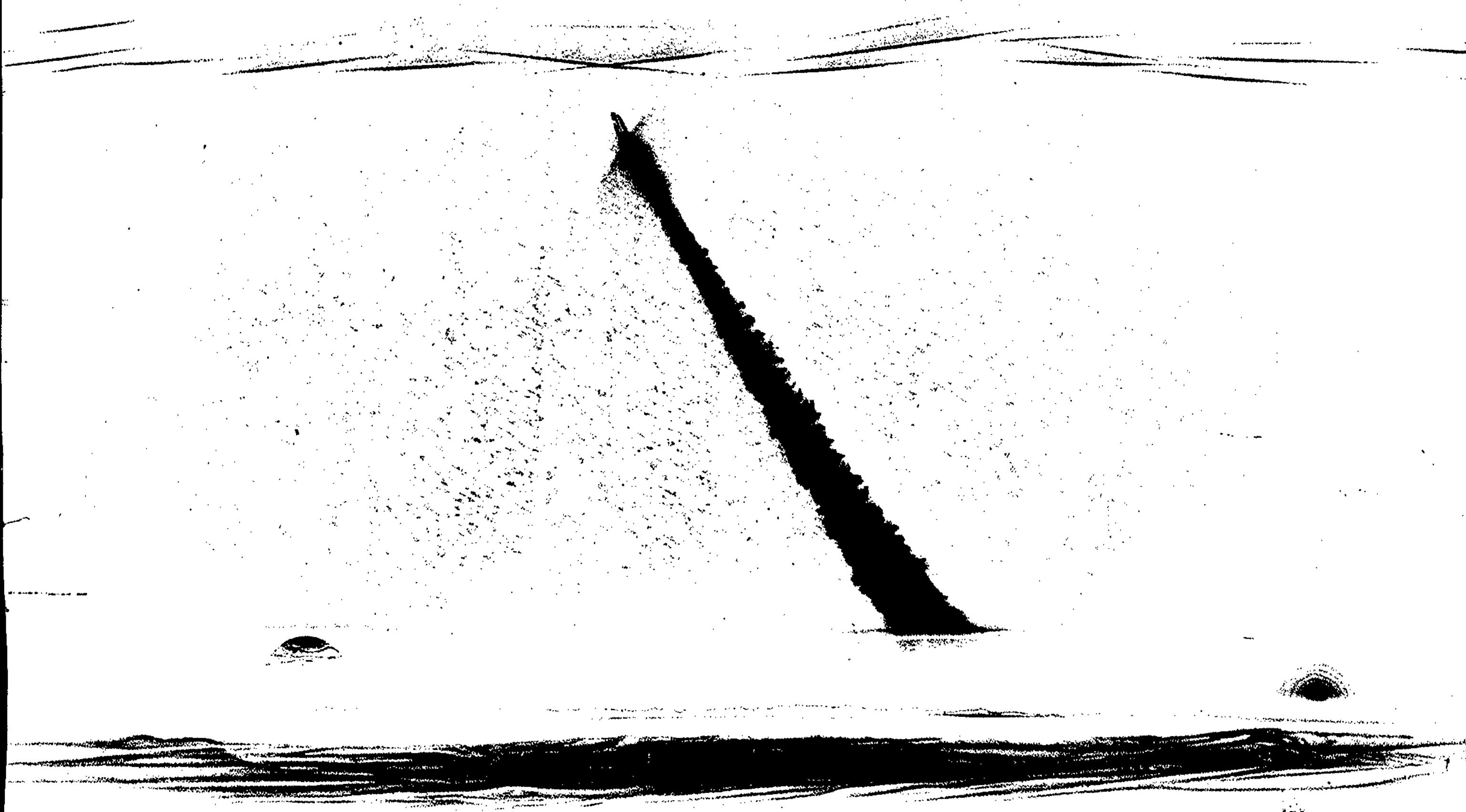
OAST
Technology For the Future

Volume II—Critical Technologies, Themes 1–4



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IN-SPACE TECHNOLOGY EXPERI

IN-STEP 88 WORKSHOP

FOREWORD

At the workshop, Dr. Harrison H. Schmitt emphasized that the nations which effectively exploit the advantages of space will lead human activities on earth. The major space goal of the National Aeronautics and Space Administration's Office of Aeronautics and Space Technology (OAST) is to provide enabling technologies, validated at a level suitable for user-readiness, for future space missions in order to ensure continued U.S. Leadership in space. An important element in accomplishing this goal is the In-Space Technology Experiments Program whose purpose is to explore and validate in space advanced technologies that will improve the effectiveness and efficiency of current and future space systems. OAST has worked closely with the aerospace community over the last few years to utilize the Space Shuttle, expendable launch vehicles, and, in the future, the Space Station Freedom for experimentation in space in the same way that we utilize wind tunnels to develop aeronautical technologies. This close cooperation with the user community is an important, integral part of the evolution of the In-Space Technology Experiments Program which was originated to provide access to space for technology research and experimentation for the entire U.S. aerospace community.

On December 6 through 9, 1988, almost 400 researchers, technologists, and managers from U.S. companies, universities, and the government participated in the OAST IN-STEP 88 Workshop. The participants reviewed the current in-space technology flight experiments, identified and prioritized the technologies that are critical for future national space programs and that require verification or validation in space, and provided constructive feedback on the future plans for the In-Space Technology Experiments Program. The attendees actively participated in the identification and prioritization of future critical space technologies in eight major discipline theme areas. These critical space technologies will help focus future solicitations for in-space flight experiments. The material within these four volumes is the culmination of the workshop participants' efforts to review the planning for the future of this program.

Dr. Leonard Harris
Chief Engineer
Office of Aeronautics and
Space Technology, NASA

OAST IN-STEP 88 WORKSHOP
Critical Technologies (Themes 1-4)

VOLUME II

INTRODUCTION TO VOLUME II

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop on the In-Space Technology Experiments Program (IN-STEP) December 6-9, 1988, in Atlanta, Georgia. The purpose of this workshop was to identify and prioritize space technologies which are critical for future national space programs and which require validation in the space environment. A secondary objective was to review the current NASA (InReach) and Industry/University (Out-Reach) experiments. Finally, the aerospace community was requested to review and comment on the proposed plans for the continuation of the In-Space Technology Experiments Program. In particular, the review included the proposed process for focusing the next experiment selection on specific, critical technologies and the process for implementing the hardware development and integration on the Space Shuttle vehicle. The product of the workshop was a prioritized listing of the critical space technology needs in each of eight technology disciplines. These listings were the cumulative recommendations of nearly 400 participants, which included researchers, technologists, and managers from aerospace industries, universities, and government organizations.

The identification and prioritization of the critical space technology needs were initiated by assigning NASA chairpersons (theme leaders) to the eight major technology disciplines or themes requiring consideration. These themes were as follows:

- space structures
- space environmental effects
- power systems and thermal management
- fluid management and propulsion systems
- automation and robotics
- sensors and information systems
- in-space systems
- humans in space

In order to provide further structure within each theme, the chairpersons divided their themes into three theme elements each. The theme element concept allowed focused technical discussions to occur within the broad discipline themes. For each theme element, the theme leader selected government, industry, and university experts to present the critical space technology needs of their respective organizations. The presentations were reviewed and discussed by the theme audiences (other members of the aerospace community), and prioritized lists of the critical technologies which require verification and validation in space were established for each theme element. The comments and conclusions for each theme were incorporated into a summary listing of the critical space technology needs and associated flight experiments representing the combined inputs of the speakers, the audience, and the theme leader.

The critical space technology needs and associated space flight experiments identified by the participants provide an important part of the strategic planning process for space technology development and provide the basis for the next solicitation for space technology flight experiments. The results of the workshop will be presented to the IN-STEP Selection Advisory Committee in early 1989. This committee will review the critical technology needs, the funding available for the program, and the space flight opportunities available to determine the specific technologies for which space flight experiments will be requested in the next solicitation.

These proceedings are organized into an Executive Summary and four volumes:Executive Summary; In-Reach/Out-Reach Experiments and Experiment Integration Process (Volume I); and Critical Technology Presentations (Volumes II and III).

Volume II contains the theme introduction given by the chairperson, the critical technology presentations for each theme element, and the summary listings of critical space technology needs for each theme. The introduction for each theme includes the chairperson's overview of the theme and its theme elements, along with instructions for the participants. The critical technology presentations are as described above, and the summaries are the listings of critical space technology needs and associated flight experiments as discussed above. This volume contains the documentation for the following four themes: space structures, space environmental effects, power systems and thermal management, and fluid management and propulsion systems.

PRESENTATION OF CRITICAL TECHNOLOGIES FOR THEMES 1-4

1. SPACE STRUCTURES

SPACE STRUCTURES
BACKGROUND AND OBJECTIVES

MARTIN MIKULAS, JR.
LANGLEY RESEARCH CENTER

ORGANIZATION

<u>THEME LEADER</u>:	Martin M. Mikulas, Jr.
<u>COMMITTEE</u>:	Murray S. Hirschbein, OAST/RM Harold Frisch, GSFC John A. Garba, JPL Dale C. Ferguson, LeRC Richard W. Schock, MSFC Robert J. Hayduk, LaRC Claude R. Keckler, LaRC Plus Subtheme Speakers
<u>SUBTHEMES &</u> <u>THEME GROUPS</u>:	1. Structures 2. Control/Structure Interaction 3. Controls

THEME SESSION OBJECTIVES

PURPOSE:

- Identify and prioritize in-space technologies for space structures by considering subtheme details which
  - are critical for future U. S. space programs.
  - require development and in-space validation.
- Generate comments and suggestions from aerospace community on OAST IN-STEP plans.

PRODUCT:

- Priority listing of critical space technology needs and associated space flight experiments, recommended by aerospace community.

THEME DESCRIPTION

SCOPE:

- Provide the technology and understanding of all three subthemes needed to develop the in-space technologies necessary to design, construct, and control large space structures with particular emphasis in structural dynamics, control/structure interaction and system identification.

BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT

- Summary of space structures theme from 1985 Williamsburg, VA workshop (see Appendix)

- Accomplishments since 1985

  - In-reach activities
  - Out-reach activities
  - Experiments in preparations
    - Mode
    - SSSCE

THEME SESSION AGENDA

SUBTHEME: STRUCTURES

		Speakers
9:45 am	Speaker 1. (30 mins.)	1. Jerome Pearson, AFWAL
	Speaker 2. (30 mins.)	2. Donald E. Skoumal, Boeing
	Speaker 3. (30 mins.)	3. Prof. K. C. Park, U. of CO
11:45 am	Discussion (30 mins.)	

SUBTHEME:CONTROL/STRUCTURE INTERACTION

1:00 pm	Speaker 1. (30 mins.)	1. Jerry Newsom, NASA LaRC
	Speaker 2. (30 mins.)	2. Joanne Maguire, TRW
	Speaker 3. (30 mins.)	3. Prof. Edward F. Crawley, MIT
3:00 pm	Discussion (30 mins.)	

SUBTHEME: CONTROLS

3:15 pm	Speaker 1. (30 mins.)	1. John P. Sharkey, NASA MSFC
	Speaker 2. (30 mins.)	2. Irving Hirsch, Boeing
	Speaker 3. (30 mins.)	3. Robert Shelton, Purdue U.
5:15 pm	Discussion (30 mins.)	

THEME DISCUSSIONS

<u>AFTER EACH SUBTHEME SESSION</u>:

- Open 30 minute DISCUSSION with audience and theme leader/speakers/panel
  - Questions and answers
  - Identification of additional technologies from audience

- Audience prioritization of critical technologies

<u>JOINT THEME DISCUSSION</u>, Thursday 8:30-10:45 am

- Discussion between audience and all theme element speakers
- Resolution of critical technologies across theme

APPENDIX

Summary of

Space Structures Theme from 1985 Williamsburg, VA In-Space RT&E Workshop

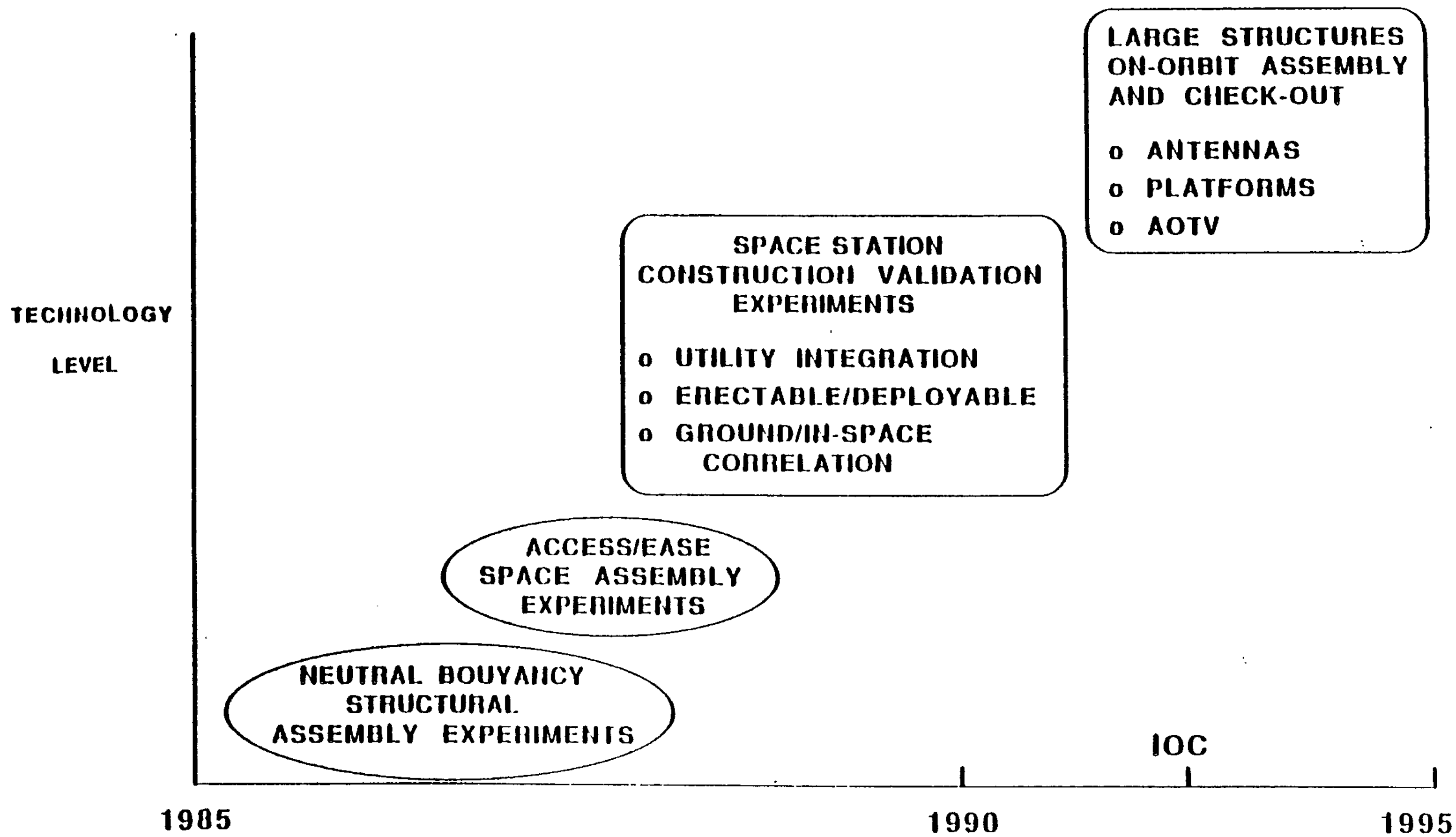
KEY STRUCTURES DYNAMICS AND CONTROL TECHNOLOGIES

1. COMPONENT TECHNOLOGY
   - SENSORS
   - ACTUATORS
2. CONTROL STRUCTURE INTERACTION
   - CONTROL TECHNOLOGY
   - STATION KEEPING
   - MANUEVERS
   - POINTING
3. SPACE STATION DYNAMIC CHARACTERIZATION
   - DYNAMIC MODELLING
4. SPACE STATION CONSTRUCTION TECHNOLOGY
   - MATERIAL BEHAVIOR
   - ASSEMBLY
   - DEPLOYMENT
5. ADVANCED STRUCTURAL CONCEPTS

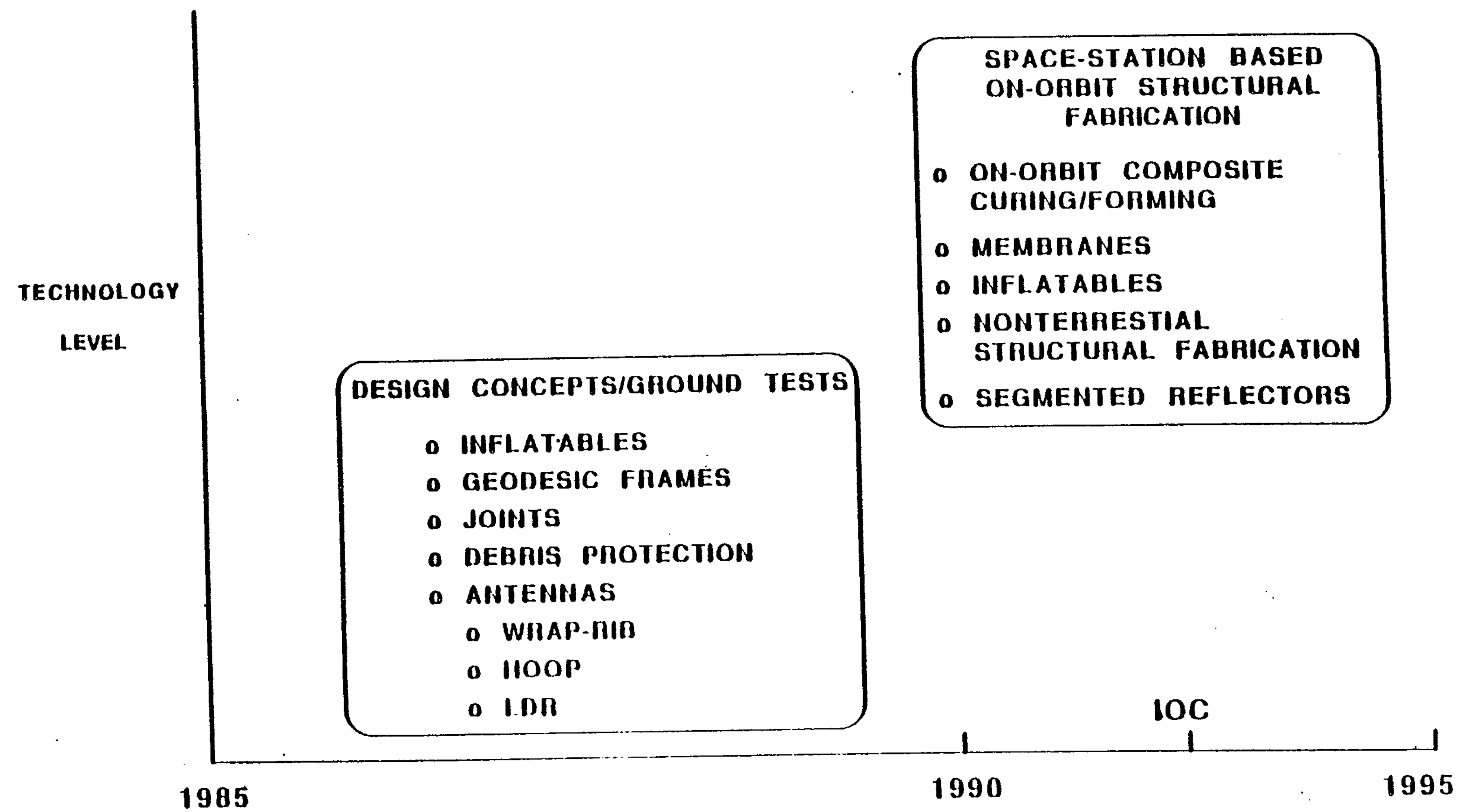
TECHNOLOGY GAPS IN PROPOSED EXPERIMENTS

- o VALIDATION OF STATION IOC CONSTRUCTION AND UTILITY INTEGRATION
- o VALIDATION OF LONG-TERM STRUCTURAL INTEGRITY
- o PASSIVE DAMPING
- o IN-SPACE LOADS CHARACTERIZATION
- o COST-EFFECTIVE HARDWARE DEVELOPMENT
- o STRUCTURALLY-EMBEDDED SENSORS/ACTUATORS
- o VIBRATION/SHAPE CONTROL DEVICES
  - SENSORS
  - ACTUATORS
- o LOW-FREQUENCY ISOLATION DEVICES

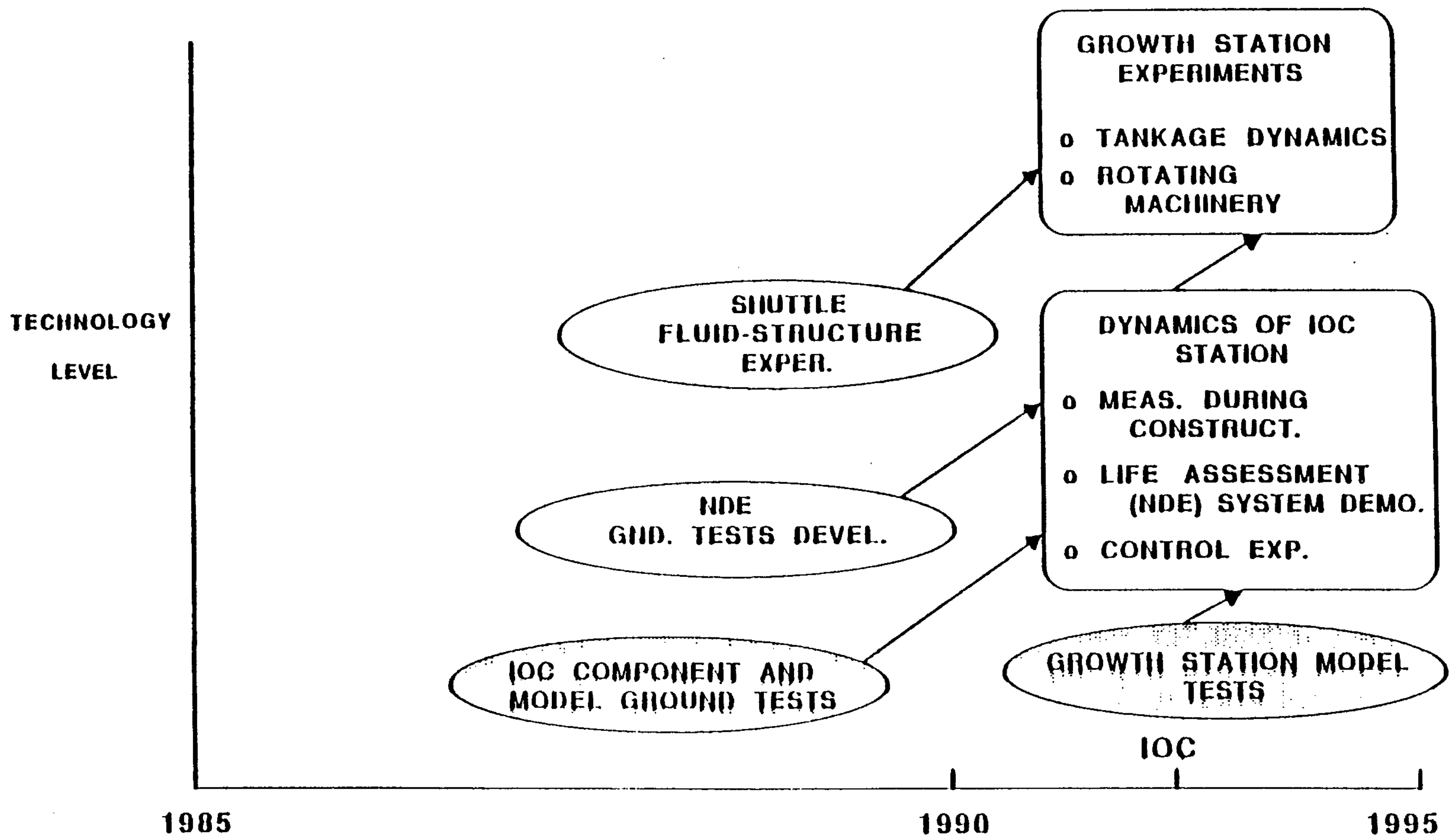
SPACE CONSTRUCTION TECHNOLOGY



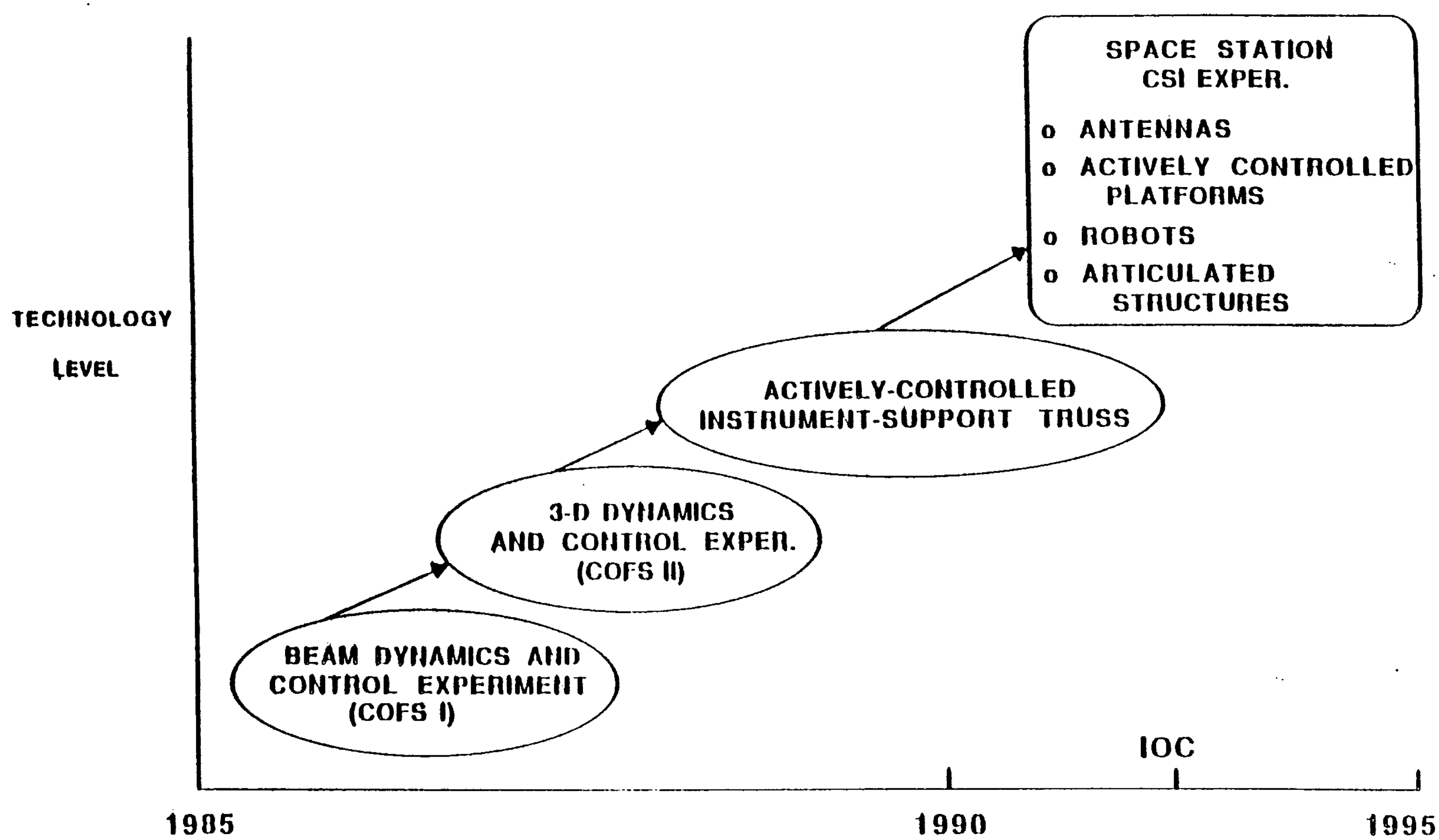
ADVANCED STRUCTURAL CONCEPTS



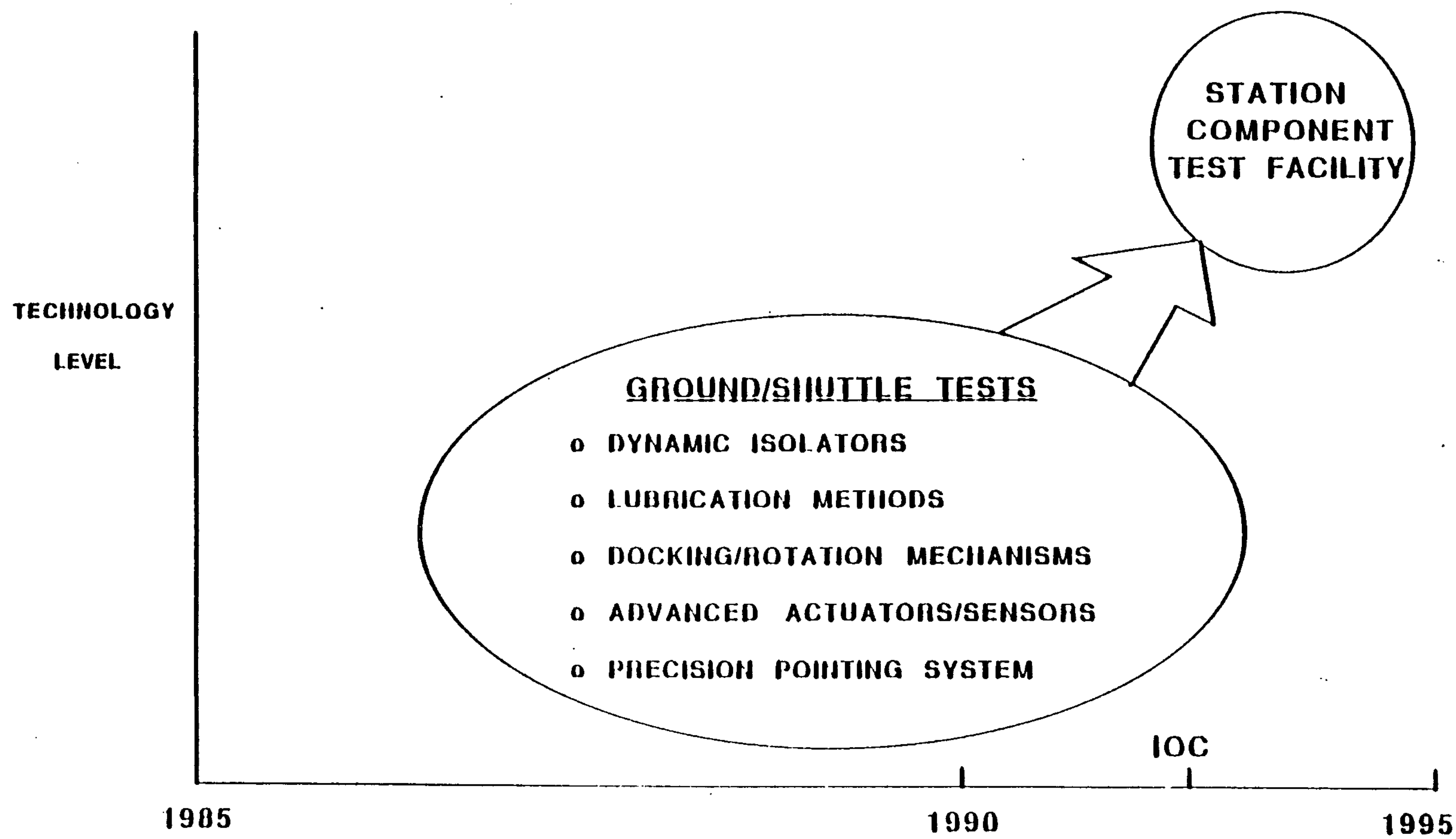
SPACE STATION DYNAMIC CHARACTERIZATION



CONTROL/STRUCTURES INTERACTION (CSI)



COMPONENT TECHNOLOGY



CRITICAL ELEMENTS NEEDED FOR DEVELOPMENT

- HIGH ACCURACY SURFACE SENSOR (MULTI DOF)
- REAL-TIME PHOTOGRAMETRIC CONCEPT
- MID-RANGE MOMENTUM ACTUATORS
- HIGH SPEED, HIGH CAPACITY FLIGHT COMPUTERS FOR CSI
- HIGH SPEED, HIGH CAPACITY DATA BASES
- MULTI-BODY ALIGNMENT TRANSFER & POINTING SYSTEM
- RELATIVE ALIGNMENT SENSOR
- VIBRATION ACTUATORS
- LOW-FREQUENCY ACTUATORS
- OPTICAL/INERTIAL VIBRATION SENSORS
- LOW-G ACCELEROMETER
- LOW-THRUSTER FOR REBOOST

1.1 STRUCTURES

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AIR FORCE STRUCTURAL DYNAMICS AND CSI TECHNOLOGY NEEDS

JEROME PEARSON

STRUCTURAL DYNAMICS BRANCH
FLIGHT DYNAMICS LABORATORY

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

INTRODUCTION/BACKGROUND

o PROPOSED SPACE SYSTEMS ARE VERY LARGE, AND INHERENTLY FLEXIBLE

- ADVANCED COMMUNICATIONS
- SPACE BASED RADAR
- SPACE STATION
- SDI SPACE BASED ARCHITECTURE

o MISSIONS CALL FOR EXTREMELY PRECISE ACQUISITION, SLEW, POINTING, TRACKING, AND FIGURE CONTROL

- MICRON DISPLACEMENT CONTROL
- NANORADIAN POINTING ACCURACIES
- AN EXTREME RETARGET CHALLENGE

o THE COMBINED IMPACT OF STRUCTURE, MISSION, AND ENVIRONMENT REQUIRES A SIGNIFICANT 'LEAP' BEYOND CURRENT CAPABILITIES.

MISSION APPLICATIONS

0 TECHNOLOGY NEEDS DRIVEN BY NUMEROUS SYSTEMS

- NEAR TERM SYSTEMS
  - SSTS/BSTS
  - ADVANCED COMMUNICATIONS
  - SPACE BASED RADAR
- FAR TERM SYSTEMS
  - SPACE BASED LASER
  - RAIL GUN
  - NPB

TECHNOLOGY NEEDS

- PASSIVE DAMPING
  - PASSIVE DAMPING DESIGN CONCEPTS
  - PASSIVE DAMPING OPTIMIZATION
  - DAMPING MATERIALS CERTIFICATION FOR SPACE

- ACTIVE CONTROL
  - HIGH EFFICIENCY, LOW MASS ACTUATORS
  - ACCURATE MULTI-POINT SENSORS
  - DISTRIBUTED SENSING/PROCESSING/ACTUATION
  - ULTRA PRECISION SENSORS/CONTROL LAWS/ACTUATORS
  - STRUCTURAL STIFFNESS/PASSIVE DAMPING/CONTROL OPTIMIZATION

- GROUND TESTING
  - SYSTEM PARAMETER IDENTIFICATION
  - MICROGRAVITY SUSPENSION
  - ULTRA-PRECISION, LOW FREQUENCY MEASUREMENTS

IN SPACE EXPERIMENTATION NEEDS/VOIDS

- SPACE TESTING TO VERIFY GROUND DYNAMIC TEST RESULTS
- ON-ORBIT SYSTEM IDENTIFICATION METHODS
- SENSOR AND ACTUATOR BEHAVIOR IN THE SPACE ENVIRONMENT
- LONG TERM SPACE EXPOSURE EFFECTS

SUMMARY/RECOMMENDATIONS

- ESTABLISH ZERO GRAVITY STRUCTURAL CHARACTERIZATION METHODS
- QUALIFY STRUCTURAL AND DAMPING MATERIALS
- QUANTIFY OPTIMAL TECHNOLOGY BLEND FOR VIBRATION SUPPRESSION
- DEVELOP FREE FLYING STRUCTURAL DYNAMICS EXPERIMENT

INDUSTRY PERSPECTIVE ON TECHNOLOGY NEEDS FOR SPACE STRUCTURES

Donald E. Skoumal
Richard M. Gates

Boeing Aerospace

December 6, 1988

INTRODUCTION / BACKGROUND

- Advanced structural concepts being defined
- Large space structures will require on-orbit construction/assembly
- Construction site/facility will impact concept design and assembly approach
- Ground testing not always feasible
- Large analytical models for in-space predictions
- Testing must simulate actual environment
- New NDE methods coming along
- In-space testing required

MISSION APPLICATIONS

- Antennas
  - Earth observation
  - Communications
- Precision reflectors
  - LDR
  - VLBI
  - SBR
- Manned spacecraft
  - Space Station
  - Manned Mars Mission

TECHNOLOGY NEEDS

- Structural concepts
  - Deployable
  - Erectable
  - Modular
  - Smart structure
- Construction techniques
  - Deployment
  - Manual assembly
  - Fabrication
  - Robotic assembly
  - Repair/maintenance
- Structural characterization
  - As-built accuracy
  - Dynamic characteristics
  - Health monitoring
  - Measurement techniques

TECHNOLOGY NEEDS (Continued)

- Ground test methods
  - Components/assemblies
  - Scaled models
  - Zero spring rate supports

- Analytical prediction techniques
  - Model fidelity
  - Multi-body issues
  - Nonlinear representations (joints, friction)
  - Structure/wavefront interaction (CSI)

- Sensor/actuator technology
  - Embedded devices
  - Conventional

IN-SPACE EXPERIMENTATION NEEDS / VOIDS

- Construction techniques
  - Deployment
  - Assembly (manual, robotic)
  - Fabrication
  - Repair/maintenance

- Structural characterization techniques
  - Quasi-static (as-built accuracy, thermal deflections)
  - Dynamic (mode shapes, frequencies, damping, non-linearities)

- Sensor/actuator technology verification
  - Embedded devices
  - Optical/laser measurement systems

IN-SPACE EXPERIMENTATION NEEDS / VOIDS (Cont'd)

- NDE methods for In-Space applications
  - Structural characterization
  - Damage detection and isolation

- Space Station Facility for Technology Demonstrations

SUMMARY / RECOMMENDATIONS

Need Cohesive Interdisciplinary Plan:

- Innovative Structural Concepts
- Compatible Construction Approaches
- Improved Ground Test Methods
- In-Space Structural Characterization
- Model Verification and Long Life Integrity through In-Space Technology Demonstrations

University Participation in In-Space Technology Experiments on Space Structures

K.C. Park
Center for Space Structures and Controls
University of Colorado
Boulder, CO 80309-0429

In-Space Experiments Criteria for University

- Maximum Student and Multi-Institution Participation
- Experiments That Lead to New Analytical Research
- Progressive Difficulty in Design and Instrumentation
- Experiments That Provide Real-World Experience and Will Be Adopted by NASA
- Multi-Disciplinary Features: Structure-Dynamics, Structure-Control, Structure-Robotics

Technology Needs for University Space Structures Program

- Structures Discipline:
  - In-Space Construction: Deployment/Assembly Simulation Validation
  - LSS Modeling and System Identification
  - Structural Modifications and Dynamic Stability
  - Design and Test of Fully Instrumented Structures
  - Joining/Assembly Design and Test Methods

Technology Needs for University Space Structures Program

- **Structures–Other Discipline Fertilization:**
  - **Articulation and Maneuvering of Structures by Space Crane**
  - **Smart Structural Elements and Active Controls**
  - **Accurate Pointing of Flexible Manipulator Tip**
  - **Tether Retrieval and Retrieval Platform Dynamics**
  - **Thermal Transients and Shape Control**

Candidate In-Space Experiment Needs
for
University Space Structures Program

Progressively Instrumented Space Crane

- Repetitive Usage for Several Experiments
- Long-Term Involvement of Students
- Interdisciplinary Activities (i.e., Controls, Dynamics, Robotics, Instrumentation)
- Models and Experimental Data Can Be Shared by Many Institutions

Candidate In-Space Experiment Needs for University Space Structures Program

Proposed Experiments for Scale-Model Space Crane

Experiment	Description
#1	Ground Test of Assembly and Dynamics
#2	Motion Study of Assembly Procedures and Dynamics
#3	Re-Design of the Model Crane
#4	Articulation and Controls
#5	Environmental/Operational Loads Identification
#6	Full Instrumentation and Systems Integration
#7	Use of Space Crane for Construction Demands

1.2 CONTROL/STRUCTURE INTERACTION

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AN OVERVIEW OF THE NASA CONTROLS-STRUCTURES-INTERACTION PROGRAM

J NEWSOM
LaRC

H. WAITES
MSFC

W. LAYMAN
JPL

THE NASA CONTROLS-STUCTURES INTERACTION (CSI) PROGRAM

- A RESTRUCTURING OF THE COFS PROGRAM
- EMPHASIZES INCREASED GROUND TESTING AND ANALYTICAL METHODOLOGY DEVELOPMENT WITH A CONSERVATIVE FLIGHT EXPERIMENT SCHEDULE
- SPACECRAFT APPLICATIONS WEIGHTED TOWARD SCIENCE MISSIONS FOR THE 2000+ TIME FRAME
- JOINT EFFORT OF NASA HEADQUARTERS, LANGLEY, MARSHALL AND JPL

CSI TECHNOLOGY NEEDS

- QUANTIFICATION OF MISSION REQUIREMENTS AND BENEFIT TRADE-OFFS
- INTEGRATED MODELING, ANALYSIS, AND CONTROL/STRUCTURE DESIGN APPROACHES
- GROUND TEST METHODS FOR VERIFYING CSI DESIGNS
- SELECTED IN-SPACE FLIGHT EXPERIMENTS TO QUANTIFY ACCURACY OF GROUND-BASED PREDICTIONS

IN-SPACE FLIGHT EXPERIMENT PLANNING

APPROACH

- DEFINE CSI ELEMENTS REQUIRING FLIGHT TESTING ("NEEDS" ASSESSMENT)
- DEFINE APPROACHES FOR REDUCING FLIGHT EXPERIMENT COSTS (LOW-COST SYSTEMS STUDY)
- QUANTIFY TECHNOLOGY RETURN FROM CANDIDATE EXPERIMENT OPPORTUNITIES (POTENTIAL RETURN EVALUATIONS)

FLIGHT EXPERIMENT PLANNING

LOW-COST SYSTEMS STUDY

- TAKE ADVANTAGE OF EXPERIMENTAL NATURE---

- SHORT DURATION	- PREDICTABLE PERFORMANCE
- RETEST OPPORTUNITY	- INHERENT REDUNDANCY

TO RELAX REQUIREMENTS AND REDUCE COST---

- OPERATING LIFE	- RELIABILITY
- QUALITY CONTROL	- TRACEABILITY
- PERFORMANCE TOLERANCES	- NOISE GENERATION

- TRADE:

SHUTTLE-ATTACHED VS FREE FLYERS

SUMMARY

- CONTROLS-STRUCTURES INTERACTION (CSI) IS A KEY ENABLING TECHNOLOGY FOR FUTURE NASA SPACECRAFT

- PROPER IMPLEMENTATION OF CSI TECHNOLOGY PROMISES SIGNIFICANT IMPROVEMENTS IN CAPABILITY AT LESS COST

- CSI IS EFFECTIVELY A NEW DISCIPLINE WHICH ENCOMPASSES AND INTEGRALLY MERGES STRUCTURES AND CONTROLS

- NASA HAS EMBARKED ON A MAJOR MULTI-CENTER EFFORT TO DEVELOP THIS TECHNOLOGY FOR PRACTICAL APPLICATION IN SPACECRAFT

- A CONSERVATIVE FLIGHT EXPERIMENT APPROACH IS PLANNED

  -ON-ORBIT TEST WHEN READY AND <u>NEED</u> EXISTS

  -STUDY WAYS TO REDUCE FLIGHT <u>EXPERIMENTS</u>

  -STUDY ADVANTAGES/DISADVANTAGES OF SMALL-SCALE VS LARGE-SCALE FLIGHT EXPERIMENTS

TECHNOLOGY DEVELOPMENT NEEDS: INDUSTRY PERSPECTIVE

Carolyn S. Major

TRW Space & Technology Group

INTRODUCTION/BACKGROUND

- CSI technology motivated by many future missions
  - Large flexible structures
  - Precision pointing and agility
- Research in CSI dates to mid '70's
- Plethora of ground experiments (government, academia, industry)
- Several space experiments planned but thwarted (e.g., ACOSS, ACE, COFS)

MISSION APPLICATIONS

Missions	Constituent Parts			
	Deployable Reflectors	Segmented Optics	Articulated Payloads	Flexible Appendages
SBL		X	X	
SBR	X		X	
EOS			X	X
VLBI			X	X
LDR	X	X		
SSTS			X	X
A-TDRS	X		X	X

TECHNOLOGY NEEDS

- Improved modeling
  - beyond NASTRAN
  - non-linear multibody dynamics
- On-line system identification and adaptive control
- Integrated controls/structures design approaches
- Coordinated control system design techniques: slew and point, active and passive
- Component development
  - embedded sensors & actuators
  - space qualified parallel processor
  - light-weight active isolators

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- Modeling, identification & components must be proven via space experimentation
- Design methodologies can be developed and proven with rigorous ground experiments

SUMMARY/RECOMMENDATIONS

- Piggy-back CSI hardware & software on appropriate near-term missions for cost-effective, timely validation
  - Vehicle accommodation of CSI equipment (weight, power, data handling)
  - Requirements for additional a priori testing
- Proceed with top-down ground experiment with well-defined mission requirements to further design methodologies

THE NEED FOR SPACE FLIGHT EXPERIMENTATION IN CONTROL / STRUCTURE INTERACTION

Edward F. Crawley

Space Engineering Research Center

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ARE THERE MISSIONS WHICH NEED CSI?

- Space Science -
  - Astronomical
  - Multi Payload Platforms
  - Planetary Exploration
  - Fundamental Physics
  - Micro Gravity
- Commercial/Transportation
  - Communications
  - Infra Structure
- Defense

SERC APPROACH

Rather than examine specific missions, extract common configuration themes, and associated requirements

- Two point alignment (e.g., Masking instruments)
- Multipoint alignment (e.g., Interferometer)
- Precision surface control (e.g., Reflector, collector)
- Multi sensor isolation (e.g., Platforms)
- Multibody articulation (e.g., Planetary exploration)
- Micro gravity environment maintenance (e.g., Materials)
- Large system attitude stabilization (e.g., Physics)
- Other defense configurations
- Non space configurations

CLASSES OF TECHNOLOGY NEEDS

SERC has identified the following critical technology needs:

System Architecture

Structural Concepts

Control for Structures

Structures for Control

Hardware Development

Test and Verification

SYSTEM ARCHITECTURE AND STRUCTURAL CONCEPTS

- System architecture -
  - Identify disturbance sources, transmission paths and performance critical locations
  - Minimize disturbances through selection of spacecraft systems and layout
- Structural concepts -
  - Develop precision construction or deployment techniques
  - Provide ability to reconfigure structure using mechanisms which carry static loads passively
  - Design for zero CTE, large size, long lifetime and low density

CONTROL FOR STRUCTURES AND STRUCTURES FOR CONTROL

- Control for structures
  - Hierarchic control
  - Control using intelligent materials
  - Actuator and sensor staging for enhanced dynamic range and bandwidth
  - Techniques based upon alternate modelling techniques
- Structures for control
  - Provide required passive damping
  - Provide frequency regimes for controller rolloff where modes are suppressed
  - Modeling of micro-dynamics

HARDWARE DEVELOPMENT AND TEST AND VALIDATION

Hardware development -

- Space-realizable sensors and actuators
- Spatially continuous sensors
- Dual function actuators/sensors
- Expand the numbers and types of available flight sensors, actuators and computers

Test and validation -

- Provide the ground test program to which flight test data is to be correlated
- Identify unknowns and unmodelled aspects of plant
- Verify that control hardware and software is effective and robust

THREE POTENTIAL ROLES OF CSI SPACE FLIGHT EXPERIMENTS

- Investigation of basic technology, to understand a fundamental gravity dependence in the physics of the problem
- Demonstration of capabilities, to increase confidence in the maturity of CSI technology
- Development of a spacecraft qualification procedure, to be used in the "flight test" of future vehicles which use CSI technology

1.3 CONTROLS

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SPACE STRUCTURES

CONTROLS

HENRY B. WAITES
MSFC

ORGANIZATION: ED12 CHART NO.:	MARSHALL SPACE FLIGHT CENTER VALIDATION: GROUND AND IN-SPACE	NAME: H. WAITES DATE: DECEMBER 1988

GENERAL PLAN

- o ANALYTICAL MODELING
- o HARDWARE TESTING
  - oo OPEN LOOP
    - \- EXCITATION
    - \- SENSORS
    - \- TELEMETRY
    - \- DATA REDUCTION
  - oo CLOSED LOOP
    - \- EXCITATION
    - \- SENSORS
    - \- TELEMETRY
    - \- DATA REDUCTION
- o VALIDATION
  - oo MODEL COMPARISON
  - oo MODEL CHANGES OR UPDATES

ORGANIZATION: ED12	MARSHALL SPACE FLIGHT CENTER	NAME: H. WAITES
CHART NO.:	VALIDATION: GROUND AND IN-SPACE	DATE: DECEMBER 1988

GENERAL PLAN (CONTINUED)

- o PROGRAMS
  - oo GROUND FACILITIES (MSFC)
    - SINGLE STRUCTURE (SS) LAB (CA, ASU, CRU, VCOSS-II, ACES I-IV)
    - MULTI-STRUCTURE (MS) LAB (CASES, POF, ASO, ASOR)
    - MULTI-BODY MODELING VERIFICATION AND CONTROL (MMVC) LAB
    - ROBOT ENHANCEMENT (RE) LAB
  - oo IN-FLIGHT
    - IPS
    - SAFE-I
    - CASES

ORGANIZATION: ED12	MARSHALL SPACE FLIGHT CENTER	NAME: H. WAITES
CHART NO.:	VALIDATION: GROUND AND IN-SPACE	DATE: DECEMBER 1988

ANALYTICAL MODELING

- o MASS
- o STIFFNESS
- o GEOMETRY
- o BOUNDARY CONDITIONS
- o SEISMIC AND SUPENSION EFFECTS
- o NONLINEARITIES
- o METHODS

ORGANIZATION: ED12	MARSHALL SPACE FLIGHT CENTER	NAME: H. WAITES
CHART NO.:	VALIDATION: GROUND AND IN-SPACE	DATE: DECEMBER 1988

HARDWARE TESTING

- o SUPPORT STRUCTURE
- o EXCITATION
  - oo BANDWIDTH AND OTHER LIMITS
  - oo INTERFACES (CONNECTIONS, CABLES, ETC.)
  - oo LOCATION(s)
  - oo CALIBRATION AND MONITORING
  - oo TELEMETRY
- o SENSORS
  - oo BANDWIDTH AND OTHER LIMITS
  - oo INTERFACES
  - oo LOCATION(s)
  - oo CALIBRATION AND MONITORING
  - oo TELEMETRY
- o OPEN LOOP
  - oo IMPACT OR IMPULSE
  - oo SINGLE AND MULTI-POINT RANDOM
  - oo SINE DWELL

HARDWARE TESTING (CONTINUED)

- o OPEN LOOP (CONTINUED)
  - oo SINE SWEEP
  - oo COHERENCE
  - oo LINEARITY
    - RECIPROCITY
    - EFFECTORS LEVELS
  - oo NONLINEARITY
    - IN-THE-LARGE
    - IN-THE-SMALL
  - oo EIGENVALUES AND EIGENVECTORS
- o CLOSED LOOP
  - oo TRANSFER FUNCTIONS
  - oo EIGENVALUES AND EIGENVECTORS
  - oo CONTROLS STRUCTURES INTERACTION

ORGANIZATION: ED12	MARSHALL SPACE FLIGHT CENTER	NAME: H. WAITES
CHART NO.:	VALIDATION: GROUND AND IN-SPACE	DATE: DECEMBER 1988

VALIDATION

- o MODEL(s) VS TEST CONFIGURATION(s)
- o MODEL CHANGES AND UPDATES
    - oo MASS
    - oo STIFFNESS
    - oo GEOMETRY
    - oo BOUNDARY CONDITIONS
    - oo SEISMIC AND SUSPENSION AFFECTS
    - oo DAMPING
- o UPDATED MODEL VS TEST CONFIGURATION
- o TRANSITION MODEL

ORGANIZATION: ED12	MARSHALL SPACE FLIGHT CENTER	NAME: H. WAITES
CHART NO.:	VALIDATION: GROUND AND IN-SPACE	DATE: DECEMBER 1988

EXAMPLES

- o SS LAB
- o IPS
- o SAFE-I
- o FUTURE PROGRAMS

INDUSTRY PERSPECTIVE ON CONTROL TECHNOLOGY NEEDS FOR SPACE FLIGHT VERIFICATION

Irving Hirsch

MISSION APPLICATIONS

Class/Example	Typical Issues
• Large flexible spacecraft • Large deployable reflector • Very large optical interferometer	• Space assembly (handling/robotics) • Jitter control/precision pointing/ shape control
• Manned spacecraft • Space station • Manned Mars mission	• System identification • Precision appendage articulation • Space assembly (handling/robotics)
• Planetary exploration • Mars sample return mission	• Smart autonomy • Robustness • Precision appendage articulation
• Earth observation • Satellites • Tethers	• Precision appendage articulation • Stability/robustness
• Space transportation vehicles • Advanced Launch System • Shuttle C• • Orbital transfer vehicles	• Robustness • Adaptive control and estimation TVC actuation

TECHNOLOGY NEEDS

- Modeling and simulation
  - Accurate structural representations within control bandpass
  - Fluid flow interactions
  - Nonlinear joint response characterization
  - Realistic nonlinear controls component models
  - Accurate large-angle and slewing motion representations for flexible structures
  - Accurate translational connection representations for maneuvering and docking or grappling

- Controls algorithms
  - Hierarchical and distributed control architectures
  - Application of robust and/or adaptive control theory
  - Nonlinear control methodology
  - Software redundancy for failure detection, isolation and reconfiguration of multiple sensors/actuators
  - Parallel processing (e.g., neural networks)

TECHNOLOGY NEEDS

(Continued)

- Controls components
  - Magnetic suspension control moment gyros (CMG's)
  - Throttlable thrusters for proportional control
  - 'Smart' structures (i.e., embedded actuators/sensors)
  - Wavefront, surface shape, and alignment sensors
  - Fault-tolerant digital computers and interfaces
  - Low-g accelerometers
  - Low cost, low weight components
  - Passive damping elements
  - Electro mechanical actuators with redundancy

- Design and analysis tools
  - Common database executive and interface programs
  - Integrated system analysis and design optimization

TECHNOLOGY NEEDS

(Continued)

- Verification simulation and test
  - Large-scale hardware-in-loop (HIL) simulators
  - Soft and air-bearing suspensions for large systems
  - Magnetic suspension for precision pointing and vibration isolation (in-space?)
  - Vision and force control test capability for robotics (in-space?)
  - Surface shape and wavefront control test capability (in-space?)

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- Instrument and system identification of 'planned' spacecraft to quantify structural dynamics and correlate with ground test results (e.g., 'high frequency' space station modes and damping)
    - Joints unloaded in space
    - Micro-g environment
- Robotics assisted structural assembly
    - Astronaut interfaces
- Precision articulation/vibration isolation
    - Control hardware nonlinearities
    - Micro-g environment
- Advanced component technology verification
    - Non-ground testable

SUMMARY/RECOMMENDATIONS

- Control Technology gaps exist for space flight verification
- Many of these gaps can be cost effectively reduced by analysis, simulation and ground test
- Some in-flight test verification is still required
- Technology gaps in other subthemes overlap control technology gaps
- A detailed space flight verification plan is required for integration with other subthemes

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EXPERIMENTS IN DYNAMICS & CONTROLS

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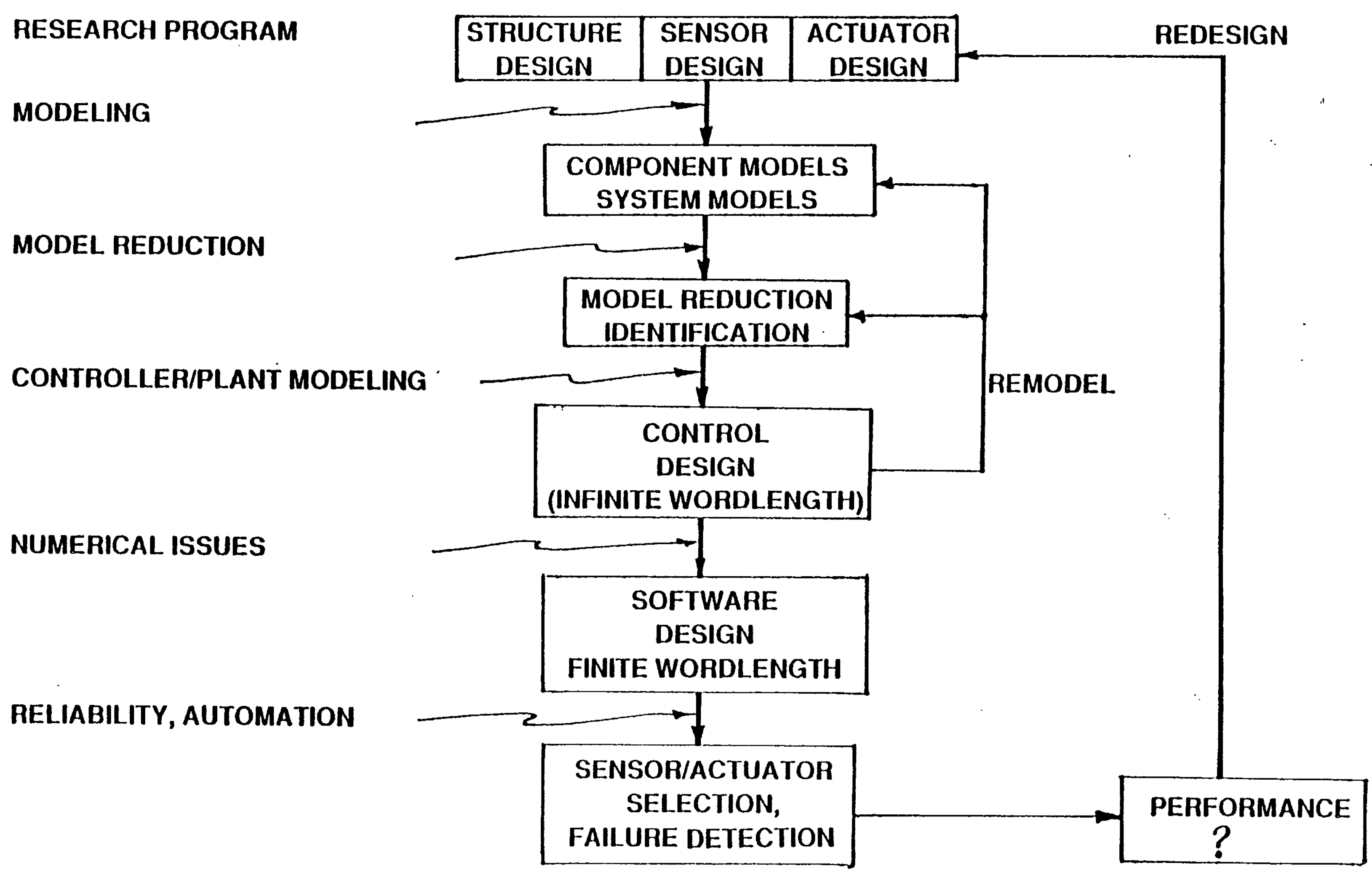
INTRODUCTION / BACKGROUND

- LESSONS FROM THE PAST
- GUIDING PRINCIPLES
- THEORY NEEDS
- SOFTWARE NEEDS
- HARDWARE NEEDS
- THEME PROBLEMS, EXPERIMENTS

STRUCTURES (DYNAMICS AND CONTROLS)	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CONTROLS



THEORY NEEDS

- MULTIPLE PERFORMANCE GUARANTEES
- ROBUSTNESS GUARANTEES
- NUMERICAL ISSUES IMBEDDED IN CONTROLLER DESIGN
- THEORY OF DESIGN INTERATIONS
  (CONVERGENCE)
- IMPACT ON HARDWARE COMPONENT DESIGN
  (SUBSYSTEM SPECS FROM SYSTEM GOERS)

SOFTWARE NEEDS

- DESIGN WORKSTATIONS
  (FOR FAST DESIGN ITERATIONS)
  (GRAPHIC PRESENTATION OF TRADEOFFS)

- OPTIMIZING SIMULATIONS FOR MAXIMAL ACCURACY COMPUTATIONS

- OPTIMIZING CONTROLLER SOFTWARE FOR MAXIMAL ACCURACY COMPUTATIONS

- OPTIMAL TRADEOFFS BETWEEN HARDWARD/SOFTWARE IN SIMULATIONS AND LAB EXPERIMENTS

HARDWARE NEEDS

- NEW SENSORS
  - OPTIMAL NOISE LEVELS (FROM COMPONENT SPECS)
  - POSITION, RATE, ACCELERATION, STRAIN
  - DISTRIBUTED, RELIABLE, HARDENED
- NEW ACTUATORS
  - OPTIMAL NOISE LEVELS (FROM COMPONENT SPECS)
  - CURRENT, VOLTAGE, TORQUE, MOMENTUM EXCHANGE, MASS DISTRIBUTION,
- NEW COMPUTERS TAILORED TO FLIGHT CONTROL NEEDS
  - PARALLEL PROCESSING?
  - MULTIPLE WORD LENGTH & SAMPLE RATES?
- NEW LAB EXPERIMENTS TO TRADEOFF DESIGN METHODOLOGIES

THEME PROBLEMS

- NEEDED AT EVERY LEVEL.
  - ANALYTICAL EXPERIMENTS
    - PDE VS ODE
    - MODEL REDUCTION
    - CONTROL DESIGNS
  - NUMERICAL EXPERIMENTS SIMULATION
    - IDENTIFICATION IN CLOSED LOOP
    - ADAPTIVE CONTROLLERS
    - ROBUST CONTROLLERS
    - N-BODY GENERATION PROGRAMS
  - HARDWARE EXPERIMENTS
    - ACTUATORS
    - SENSORS
    - CLOSED LOOP

SUMMARY/RECOMMENDATIONS

- DEVELOP FLEXIBLE STRUCTURE THEME PROBLEMS AT 3 LEVELS:
  - ANALYTICAL EXPERIMENTS
  - NUMERICAL EXPERIMENTS
  - HARDWARE EXPERIMENTS (LAB, FLIGHT)
- TO TEST
  - MODELING FOR CONTROL DESIGN
  - CLOSED LOOP IDENTIFICATION AND CONTROL REDESIGN
  - SENSOR/ACTUATOR DESIGN, CONFIGURATION
  - COMPUTATIONAL ISSUES
    - WORDLENGTH
    - ACHITECTURE (PARALLEL, ARRAY, ETC.)
    - DECENTRALIZED COMPUTING

SPACE STRUCTURES
CRITICAL TECHNOLOGY REQUIREMENTS

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OBSERVATION

- o PEOPLE ARE ASKING FOR
  - MULTIDISCIPLINARY EXPERIMENTS
  - REUSABLE TEST BEDS
- o POTENTIAL TEST BEDS
  - SPACE STATION
  - PSR - SHUTTLE BASED
  - ?

SPACE EXPERIMENT
TECHNOLOGY NEEDS AREAS
(STRUCTURES, DYNAMICS, AND CONTROLS)

- CONTROL / STRUCTURES INTERACTION EXPERIMENTS
- STRUCTURAL CHARACTERIZATION EXPERIMENTS
- IN-SPACE CONSTRUCTION EXPERIMENTS

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP
DECEMBER 6-9, 1988

CSI/SYSTEMS
TECHNOLOGY NEEDS

	NEEDED EXPERIMENTS	
	FOR FUND. TECH. DEV.	FOR DEMO. OF TECH MATURITY
FLEXIBLE MULTI-BODY / ARTICULATED CONTROL	SPACE	SPACE
PRECISION POINTING AND SHAPE DIMENSIONAL CONTROL	SPACE	SPACE
MULTIPLE INTERACTING CONTROL SYSTEM	SPACE (?)	SPACE
DAMPING AND VIBRATION SUPRESSION	GROUND	SPACE (?)
VIBRATION ISOLATION	GROUND	SPACE (?)
ACTIVE BALANCING	GROUND	GROUND

CSI / COMPONENTS

TECH ISSUES

- ACTUATORS, SENSORS AND PROCESSORS
  - SHOULD ONLY BE TESTED IN SPACE AS AN INDIVIDUAL COMPONENT WHEN FUNDAMENTAL CHANGES IN CHARACTERISTICS ARE EXPECTED IN SPACE (E.G., RADIATION ON A COMPUTOR, GRAVITY ON AN INERTIAL SENSOR)
  - OTHERWISE SHOULD ONLY BE TESTED IN SPACE AS PART OF A SYSTEM

CRITERIA FOR SELECTING AN EXPERIMENT FOR SPACE TESTING

- BASIC PRINCIPLE
  - SPACE TESTING IS JUSTIFIED FOR FUNDAMENTAL TECHNICAL DEVELOPMENT ONLY IF THE EXPERIMENT CANNOT BE CONDUCTED ON EARTH OR WILL PRODUCE DISTORTED AND UNCORRECTABLE DATA WHEN CONDUCTED ON EARTH.

- APPLIED TO CSI
  - MIS-MODELING OF STRUCTURES AND "ZERO-G" SUSPENSIONS CAN MASK SINGULARITIES IN THE CONTROL / STRUCTURE SYSTEM WHICH CAN BE EVIDENCED ON-ORBIT BY SYSTEM INSTABILITY.
  - THERE IS NO WAY OF GUARANTEEING THRU ON-ORBIT OPEN LOOP TESTING OR GROUND BASED CLOSED LOOP TESTING THAT THE SYSTEM WILL BE STABLE ON ORBIT AT DESIGN GAIN LEVELS.

STRUCTURAL CHARACTERIZATION TECHNOLOGY NEEDS

- o SYSTEM IDENTIFICATION
  - QUASI-STATIC
    - o AS-BUILT
    - o THERMAL DEFORMATIONS
  - DYNAMIC (OPEN LOOP AND CLOSED LOOP)
    - o STRUCTURAL DYNAMICS
    - o FLUID / STRUCTURE (SLOSH, FLOW)
  - DISTURBANCE SOURCE IDENTIFICATION
- o SENSOR DEVELOPMENT
  - PRECISION DYNAMICS DUE TO LOW LEVEL EXCITATION
  - STATIC SHARE SENSORS
  - DISTURBANCE QUALIFICATION

STRUCTURAL CHARACTERIZATION TECHNOLOGY NEEDS
(Cont.)

- o VERIFICATION OF PREDICTION METHODS
  - SCALE MODELS
  - COMPONENT GROUND TESTING
  - ANALYSIS
- o STRUCTURAL INTEGRITY
  - HEALTH MONITORING
  - NDE

STRUCTURAL CHARACTERIZATION IN-SPACE EXPERIMENT JUSTIFICATION

- ELIMINATES GROUND TEST LIMITATIONS
  - GRAVITY EFFECTS
  - SUSPENSION SYSTEMS
  - SIZE LIMITATIONS
  - TERRESTRIAL DISTURBANCES THAT MASK THE PHYSICS
- ALLOWS SMALL SCALE EFFECTS TO BE IDENTIFIED
  - DAMPING
  - NONLINEARITIES
  - SENSOR CHARACTERISTICS
- PROVIDES REALISTIC TEST RESULTS FOR ANALYSIS VERIFICATION

IN-SPACE CONSTRUCTION EXPERIMENTS (TECHNOLOGIES CONSIDERED)

- o DEPLOYABLE STRUCTURES
  - LARGE TRUSSES (SPACE STATIONS SIZE)
  - 10 - 15 METER HARD SURFACE REFLECTORS
  - 40 METER HARD SURFACE REFLECTORS
  - 55 METER MESH ANTENNAS
  - INFLATABLES (15-30 METERS)
- o ERECTABLE STRUCTURES
  - SPACE STATION
  - PRECISION SEGMENTED REFLECTOR (EVA ON SHUTTLE)
  - PRECISION SEGMENTED REFLECTOR (ROBOTIC / EVA)
- o MAINTENANCE AND REPAIR

TEST BED OBJECTIVE

- o DEVELOP TECHNOLOGY ENABLING THE CONSTRUCTION AND OPERATION OF FUTURE SPACE CRAFT

APPROACH

- o EVOLUTIONARY TESTBED
  - EACH PHASE IS A FRACTION OF THE COST
  - NEW TECHNOLOGY CAN BE ADDED MIDSTREAM
- o MULTIDISCIPLINARY TESTBED
  - LOOK AT ALL INTERESTED ASPECTS
  - MAXIMIZE BENEFIT / MONEY
  - PROVIDE RELAVANT SCIENCE FOCUS

PSR FLIGHT CONSTRUCTION EXPERIMENT

PHASE I TASKS (STS PAYLOAD BAY)

- CONSTRUCTION / ASSEMBLY
  - TRUSS
  - SIMULATED MIRROR SEGMENTS
  - UTILITIES (SENSORS AND WIRING)
- TIMELINE VERIFICATION
  - ZERO-G VS. NEUTRAL BUOYANCY
- AS-BUILT ACCURACY VERIFICATION
  - SURFACE
  - SUBSTRUCTURE
- HUMAN FACTORS VERIFICATION
  - CREW RESTRAINTS
  - LIGHTING (VIEW FACTORS)
  - TOOLS AND ASSEMBLY AIDS
- DYNAMIC CHARACTERIZATION

PHASE II TASKS (FREE-FLYER)

- o SECOND ASSEMBLY TEST, FREE-FLYER
- o MAINTENANCE OF LONG TERM PASSIVE PRECISION
- o DISTURBANCE CHARACTERIZATION
- o DEGRADATION OF MATERIALS
- o RELIABILITY OF MEASUREMENTS

PHASE III TASKS (REVISIT)

- o REPAIRING, INSPECTION, CLEANING, SERVICING (ROBOTICS)
- o UPGRADING WITH
  - QUASI-STATIC RECONFIGURATION CAPABILITY
  - FURTHER UTILITIES (COOLANTS, FLUIDS, ETC)
  - PUMPS
  - VIBRATION ISOLATION

FURTHER PHASE TASKS

- PHASED INCREASE IN CSI COMPLEXITY LEADING TO FUNCTIONAL SPACE SCIENCE INSTRUMENT

PSR FLIGHT EXPERIMENT TEST BED

MULTIDISCIPLINARY INVOLVEMENT

	PHASE I				PHASE II	PHASE III	FURTHER PHASES
	TIMELINE	ACCURACY	HUMAN	CHARACTER			
TECHNOLOGY THEMES							
STRUCTURE	X	X		X	X	X	X
CSI		*			*	X	X
ROBOTICS	*				*	X	X
POWER & THERMAL					*	X	X
MAINTENANCE & REPAIR	*		X		X	X	X
HUMANS	X		X		X	X	X
ENVIRONMENT		*			X	X	X
FLUIDS						X	X
SENSORS		X		X	X	X	X
USERS							
OBSERVATORIES		*			*	*	X
MATERIAL DEVELOP.		X		X	X	X	X
PHYSICS				X	X	X	X

* SET SPECIFICATION

X RECEIVE DATA

2. SPACE ENVIRONMENTAL EFFECTS

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SPACE ENVIRONMENTAL EFFECTS BACKGROUND AND OBJECTIVES

LUBERT J. LEGER
JOHNSON SPACE CENTER

SPACE ENVIRONMENTAL EFFECTS THEME GENERAL CONTENT

- THEME ADDRESS ALL ENVIRONMENTAL EFFECTS ON SPACECRAFT SYSTEMS
  - NEUTRAL AND CHARGED PORTION OF ENVIRONMENT
  - INDUCED REACTIONS/INTERACTIONS LEADING TO SURFACE, ENVIRONMENT, EQUIPMENT CHANGES
  - MICROMETEOROID/DEBRIS IMPACTS
  - ELECTROMAGNETIC RADIATION
  - CONTAMINATION
- ALL ORBIT ALTITUDES AND INCLINATIONS CONSIDERED
- EXPERIMENTS LAUNCHED ON SPACE SHUTTLE, UNMANNED LAUNCH VEHICLES, FREE FLYERS AND CONDUCTED ON SPACE STATION

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12 - 7 - 88

ENVIRONMENTAL EFFECTS SUB-THEME DEFINITION

- **SUB-THEME 1 : ATMOSPHERIC EFFECTS AND CONTAMINATION**
  - ATOMIC OXYGEN EFFECTS
  - LOCAL CHEMISTRY MODIFICATION
  - PRESSURE EFFECTS
  - DEPOSITION ON SURFACES
  - PLUME AND VENT CONTAMINANTS
  - SENSOR DEVELOPMENT
  - CONTROL TECHNIQUES
  - MEASUREMENT TECHNIQUES

- **SUB-THEME 2 : MICROMETEOROIDS AND DEBRIS**
  - SHIELD SYSTEMS
  - ENVIRONMENT DEFINITION
  - EFFECTS ON SPACECRAFT
  - DETECTION AND IMPACT CONTROL

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ENVIRONMENTAL EFFECTS SUB-THEME DEFINITION (CONTINUED)

- **SUB-THEME 3 : CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS**

  - ELECTRONIC SYSTEM EFFECTS
  - MATERIAL DAMAGE
  - SENSOR DEVELOPMENT
  - PROTECTION SYSTEMS
  - EMI / EMC
  - SINGLE EVENT UPSET
  - DOSAGE EFFECTS
  - CHARGING
  - PLASMA INTERACTIONS

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THEME SESSION OBJECTIVES

- PURPOSE
  - IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES FOR EACH THEME WHICH:
    - ARE CRITICAL FOR FUTURE NATIONAL SPACE PROGRAMS
    - REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
  - OBTAIN AEROSPACE COMMUNITY COMMENTS & SUGGESTIONS ON OAST IN-STEP PLANS
- PRODUCT
  - AEROSPACE COMMUNITY RECOMMENDED PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS

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THEME SESSION AGENDA

- THEME ELEMENT SESSIONS
  - CRITICAL SPACE TECHNOLOGY NEEDS FOR THEME ELEMENT FROM PERSPECTIVE OF:
    - INDUSTRY, UNIVERSITIES & GOVERNMENT
  - OPEN DISCUSSION WITH THE AUDIENCE & THEME ELEMENT SPEAKERS / THEME LEADER
    - QUESTION & ANSWER WITH SPEAKERS
    - IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE
- COMBINATION & PRIORITIZATION OF THEME TECHNOLOGIES
  - DISCUSSION BETWEEN AUDIENCE & ALL THEME ELEMENT SPEAKERS
  - RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME

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PRIORITIZATION CRITERIA*

1.) CRITICAL ENABLING TECHNOLOGIES

- TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U. S. SPACE MISSIONS

2.) COST REDUCTION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY (e.g., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)

3.) BROAD APPLICATION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS

4.) REQUIRE IN-SPACE VALIDATION

- TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR VALIDATION OR EXPERIMENTATION

* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1. = HIGHEST)

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2.1 ATMOSPHERIC EFFECTS AND CONTAMINATION

ATMOSPHERIC EFFECTS & CONTAMINATION

Government Perspective

Bruce A. Banks

NASA Lewis Research Center

BACKGROUND

0 Flight data from STS-3, -4, -5, -8, -41G and Solar Max

0 Most atomic oxygen does not react upon first impact

0 Lower reaction probabilities at near grazing incidence

0 Erosion yields for approximately 60 materials measured from flight tests with significant uncertainty for key materials

0 Materials which produce volatile oxidation products develop texture

0 Optical properties change (α_s, ϵ) observed

0 Basic atomic oxygen interaction processes and degradation pathways have been proposed but not fully verified

0 Influence of temperature and solar radiation on erosion yield has not been clearly determined

MISSION APPLICATIONS

0 Atomic oxygen durable materials must be identified for long duration LEO missions

0 Scattered atomic oxygen may threaten durability of materials on spacecraft interior

0 Erosion yields at low fluxes may allow use of some materials considered unacceptable at high fluxes

0 Atomic oxygen interactions must be understood in functional environment

- Temperature
- UV
- Wandering or ram attack

0 Protective coating environmental durability is required for high performance spacecraft materials and surfaces

TECHNOLOGY NEEDS

0 Erosion yield dependence upon:

- Flux
- Fluence
- Temperature
- Solar radiation

0 Scattered atomic oxygen reaction data

0 Higher certainty data for low erosion yield materials

0 Protective coating performance data

- Undercutting oxidation at pinholes, cracks, and scratches
- Diffusion
- Functional performance

0 Adequate flight data to develop algorithms to predict flight performance from ground laboratory LEO simulation

IN-SPACE EXPERIMENT NEEDS/VOIDS

0 Temperature dependency over broad range
   - Metals
   - Polymers

0 Accurate flux/fluence measurements

0 High fluence data 10^{22} - 10^{23} atoms/cm^3
   - Low erosion yield materials
   - Protected coatings
   - Evaluation of solar radiation dependence

0 Temporal erosion/reaction data

0 Scattered atomic oxygen erosion yield data

0 Functional performance evaluation of exposed materials
   - Protected or durable polymer films for solar arrays and thermal blankets
   - Radiator surfaces
   - Solar concentrators
   - Structures
   - Lubricants

SUMMARY/RECOMMENDATIONS

0 Active experiments to allow erosion yield or reaction data to be taken under variable conditions of:

- Flux
- Fluence
- Angle of attack
- Temperature
- Solar radiation

0 Scattered atomic oxygen erosion yield data

0 Active flux measurement

0 Functional evaluation of materials performance

- Mechanical
- Optical
- Thermal radiative
- Tribological

0 Adequate testing at low altitudes to develop high fluence (10^{22} - 10^{23} atoms/cm^3)

ATMOSPHERIC EFFECTS AND CONTAMINATION TECHNOLOGY DEVELOPMENT NEEDS

LYLE E. BAREISS
MARTIN MARIETTA ASTRONAUTICS GROUP
SPACE SYSTEMS COMPAY

INTRODUCTION/BACKGROUND

- CONTAMINATION DEFINED AS THE TRANSPORT OF MOLECULAR OR PARTICULATE MATERIAL TO UNDERSIREABLE LOCATIONS
- INDUCED ENVIRONMENT IN THE NEAR VICINITY OF SPACECRAFT WILL CAUSE SYSTEM/INSTRUMENT DEGRADATION
- TECHNOLOGY BASE IS INCOMPLETE AND FRAGMENTED THROUGHOUT INDUSTRY
- DEVELOPMENT OF CONTAMINANT FREE SPACE VEHICLE IS NOT CURRENTLY POSSIBLE
- FUTURE LONG TERM (10-30 YR) MISSIONS AND MORE SENSITIVE INSTRUMENTS WILL DICTATE THE NEED FOR ENHANCED UNDERSTANDING/TECHNOLOGY ADVANCES

TECHNOLOGY NEEDS

- LONG TERM CONTAMINANT SOURCE CHARACTERISTICS
  — $\dot{m} = f(T,t)$, SPECIES, STICKING
- LONG TERM DEPOSITION EFFECTS DATA
  — COMBINED ENVIRONMENT EFFECTS
- ENHANCED COMPUTER MODELING CAPABILITIES
- CONTAMINATION REMOVAL METHODS/PREVENTION TECHNIQUES
- HIGH SENSITIVITY CONTAMINATION MONITORS
  — DEPOSITION
  — OPTICAL (FIELD-OF-VIEW)

TECHNOLOGY NEEDS (CONT'D)

- NATURAL ENVIRONMENT INDUCED SOURCES
  - —DEBRIS/MICROMETEROIDS
  - —LONG TERM THERMAL CYCLING/UV DEGRADATION
  - —ATOMIC OXYGEN
- FIELD-OF-VIEW INTERFERENCE
  - —VENT/THRUSTER PLUME
  - —RANDOM PARTICULATES
  - —SURFACE OR PLUME INDUCED "GLOW"
- GROUND TESTS LIMITATIONS
  - —SIMULATING LONG TERM CHARACTERISTICS IN SHORT TERM TESTS
- FLIGHT TEST LIMITATIONS
  - —FIXED PARAMETERS
  - —SHORT MISSIONS
  - —PRIORITIES
  - —UNEXPECTED SOURCES/EVENTS

IN-SPACE EXPERIMENTATION NEEDS/VOIDS*

- LONG TERM MISSION CONTAMINATION EFFECTS
- ATOMIC OXYGEN EFFECTS MEASUREMENTS
- CONTAMINATION ABATEMENT EXPERIMENTS
  - —PURGE SYSTEMS
  - —INNOVATIVE COATINGS
  - —VOLATILE COATINGS
- IMPROVED CONTAMINATION SENSORS
  - —DEPOSITION/SURFACE EFFECTS
  - —OPTICAL ENVIRONMENT MONITORS
- ENGINE PLUME CONTAMINATION EFFECTS
  - —FLOWFIELDS
  - —DEPOSITION EFFECTS

---

* INTERNAL CONTAMINATION ISSUES ADDRESSED IN THEME AREA #4

IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- MODEL VERIFICATION EXPERIMENTS
  - —LONG DISTANCE TRANSPORT
  - —RETURN FLUX MONITORING
- ON-ORBIT CLEANING EXPERIMENTS
  - —BEAM DEVICES/LASERS/ETC
  - —USE OF AMBIENT ATOMIC OXYGEN
- SURFACE GLOW/PROMPT ENHANCEMENT MONITORS
  - —AFE TYPE RADIOMETERS/SPECTROMETERS
- CRYOGENIC DEPOSITION EXPERIMENTS
- RAM DENSITY ENHANCEMENT STUDIES
- ON-ORBIT CONTAMINATION EFFECTS EXPERIMENTS
  - —COMBINED ENVIRONMENTS
  - —CONTROLLED SOURCES
  - —PARTICLE ENVIRONMENT MONITORS

HYPERTHERMAL INTERACTIONS OF ATMOSPHERIC SPECIES WITH SPACECRAFT

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INTRODUCTION/BACKGROUND

OBJECTS IN LOW EARTH ORBIT PASS THROUGH THE AMBIENT ATMOSPHERE AT 7-8 KM/SEC. IN THE REFERENCE FRAME OF THE OBJECT THE GAS HAS AN EQUIVALENT TEMPERATURE OF 100,000°K, OR A KINETIC ENERGY (FOR O ATOMS) OF ABOUT 5eV/ ATOM. THIS IS A RELATIVELY UNSTUDIED REGION OF CHEMISTRY AND PHYSICS AND ONE WHERE ENERGETIC NEW PROCESSES MIGHT BE EXPECTED. OBSERVED PROBLEM EFFECTS INCLUDE:

- SURFACE EROSION
- SURFACE PROPERTY MODIFICATION: OPTICAL, THERMAL, ELECTRICAL
- SURFACE AND FREE-MOLECULAR GLOW
- MOMENTUM ACCOMMODATION UNCERTAINTY

TECHNOLOGY NEEDS

- O A BETTER UNDERSTANDING OF THE PHYSICS AND CHEMISTRY OF GAS SURFACE AND GAS-GAS INTERACTIONS IN THE HYPERTHERMAL REGIME IS NEEDED.

- O AN UNDERSTANDING OF THE MECHANISM OF SURFACE CHEMICAL REACTIONS WOULD ALLOW QUANTITATIVE PREDICTION OF EFFECTS FOR NEW MATERIAL-OXYGEN DOSE COMBINATIONS WITHOUT EXHAUSTIVE TESTING AND COMPLETE SIMULATION.

- O AN UNDERSTANDING OF THE SCATTERING PROCESS IS NEEDED TO PREDICT AND PERHAPS CONTROL ENERGY AND MOMENTUM ACCOMMODATION AND TO PREDICT SECONDARY EFFECTS OF SCATTERED ATOMS.

- O CHEAPER METHODS OF MONITORING THE DENSITY OR FLUX OF ATMOSPHERIC SPECIES ARE NEEDED.

TECHNOLOGY NEEDS (CONTINUED)

- NEEDED GLOW INFORMATION (IN-SPACE)

INTENSITY AS A FUNCTION OF:

- WAVELENGTH
- ALTITUDE
- VELOCITY VECTOR
- SURFACE MATERIAL
- TIME AFTER LAUNCH
- SPATIAL EXTENT

MOST IMPORTANT IS TO IDENTIFY THE SPECTRA OF THE EMITTING SPECIES

TECHNOLOGY NEEDS (CONTINUED)

- O PROBLEMS WITH SIMULATORS
  - O PRESENCE OF IONS, METASTABLE AND EXCITED ATOMS OR MOLECULES
  - O SIMULTANEOUS UV IRRADIATION
  - O UNCERTAIN BACKGROUND VACUUM CONDITIONS
  - O VELOCITY (ENERGY) PROFILE; (RATE = R(E)?)
  - O ANGULAR DISTRIBUTION PROFILE (MORPHOLOGY)
  - O FLUX RATE (R = kI?)
- O FOR EACH EXPERIMENTAL APPARATUS CONDITION AND CHEMICAL SYSTEM IT MUST BE REASONABLY WELL ESTABLISHED THAT THE ABOVE FACTORS DO NOT MATERIALLY AFFECT REACTION MECHANISMS OR MEASURED RATES.

SCATTERING STUDIES

- DYNAMICS OF SCATTERING ARE COMPLETELY DETERMINED BY THE POTENTIAL ENERGY OF INTERACTION BETWEEN ATOMS OF GAS AND SOLID.
- EXPERIMENTAL SYSTEMS CONTAIN (1) THE BEAM, (2) THE DETECTOR, AND (3) THE TARGET SURFACE.
- IDEAL MEASUREMENTS WOULD BE (IN ABSOLUTE NUMBERS OF ATOMS): VELOCITY DISTRIBUTION OF INCIDIENT BEAM AND VELOCITY DISTRIBUTION OF REFLECTED BEAM MEASURED OVER ALL ANGLES.
- VERY LITTLE DATA EXISTS ON 5 eV SCATTERING BECAUSE OF EXPERIMENTAL DIFFICULTY.
- FOR REACTIVE SCATTERING, ALSO NEED ANGULAR AND VELOCITY DISTRIBUTIONS OF PRODUCT MOLECULES

WHAT'S NEEDED TO ELUCIDATE REACTION MECHANISMS

MEASURE REACTION RATES AS FUNCTION OF:

- O MATERIAL
- O TEMPERATURE
- O OXYGEN ATOM FLUX
- O OXYGEN ATOM ENERGY

MATERIAL TYPES:

- O ALIPHATIC AND AROMATIC POLYMERS OF DIFFERENT TYPES
- O METALS
- O OXIDES
- O OTHER; EG. C, MoS_2

MANY OF THE SURFACE REACTIONS ARE COMPLEX AND MULTI-STEPPED. A VARIETY OF INSTRUMENTAL TECHNIQUES ARE NEEDED TO MEASURE THESE RATES AND MOST OF THESE STUDIES MUST BE DONE IN THE LABORATORY.

IN-SPACE TECHNOLOGY NEEDS

- IMPROVED TECHNIQUES FOR MEASURING REACTION RATES IN SPACE
- PRECISE, REPRODUCIBLE RATES MEASURED IN SPACE NEEDED FOR VERIFICATION OF SIMULATORS
- ATOMIC OXYGEN AND MOLECULAR NITROGEN DOSIMETERS
- NOVEL INSTRUMENTATION TO CHARACTERIZE IR-VISIBLE-UV GLOWS AND TEST GLOW HYPOTHESES
- IMPROVED INSTRUMENTATION FOR SCATTERING STUDIES TO VERIFY WORK AT SIMULATORS

2.2 MICROMETEOROIDS AND DEBRIS

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DETECTION AND MEASUREMENT OF THE ORBITAL DEBRIS ENVIRONMENT

FAITH VILAS

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METEOROID AND DEBRIS ENVIRONMENT

- 200 KG OF METEOROID MASS EXIST WITHIN 2000 KM OF EARTH'S SURFACE.
- 3,000,000 KG OF MAN-MADE OBJECT MASS EXIST WITHIN 2000 KM OF EARTH'S SURFACE.
- AVERAGE TOTAL INCREASE IN LEO DEBRIS HAS BEEN 5% PER YEAR.
- DEBRIS HAZARD IS LARGE ENOUGH TO AFFECT THE SPACE STATION DESIGN.
  - IMPACT DAMAGE FROM LARGE PIECES.
  - SURFACE DEGRADATION/EROSION FROM SMALL PARTICLES.

TECHNOLOGY NEEDS: NEAR TERM

- SPACE-BASED DEBRIS DETECTION SYSTEMS NEED TO BE DEVELOPED TO MONITOR LEO ENVIRONMENT IN DIFFERENT SPECTRAL RANGES.

- NEW MATERIALS AND CONCEPTS FOR SHIELDING SPACECRAFT MUST BE DEVELOPED.

TECHNOLOGY NEEDS: LONGER TERM

- SPACE-BASED COLLISION WARNING SYSTEMS NEED TO BE DEVELOPED FOR MANNED AND UNMANNED SPACECRAFT.
- DEBRIS REMOVAL SYSTEMS SHOULD BE STUDIED.
- IN-SITU METHODS OF REMOVING OR DEFLECTING A DEBRIS PIECE WHEN IMPACT IS IMMINENT MUST BE DEVELOPED.
- SPACECRAFT MATERIALS MUST BE DESIGNED WHICH WILL MINIMIZE DEGRADATION IN ORDER TO MINIMIZE FUTURE ENVIRONMENT CONTAMINATION, PRESERVE OTHER SPACE ENVIRONMENT FROM DEBRIS CONTAMINATION.

IN-SPACE EXPERIMENTS NEEDS: ENVIRONMENT DETECTION

- EXTEND DATA ON DISTRIBUTION OF DEBRIS PARTICLE SIZE WITH ALTITUDE TO PARTICLES $\leq$ 10 CM THROUGH 2000 KM ALTITUDE.
- DETERMINE MEAN ALBEDO (% REFLECTIVITY) OR ALBEDOS OF DEBRIS.
- MONITOR TEMPORAL CHANGES IN LEO DEBRIS ENVIRONMENT.
- MONITOR LEO DEBRIS ENVIRONMENT CHANGES AFTER SPECIFIC EVENTS.

IN-SPACE EXPERIMENT NEEDS: COLLISION WARNING DEVELOPMENT

- OPTIMIZE DETECTOR SELECTION FROM LEO DEBRIS THERMAL HEATING INFORMATION.
- IDENTIFY NOISE OR FALSE SIGNAL SOURCES WHICH COULD AFFECT COLLISION WARNING SYSTEMS.
- TEST DETECTOR SYSTEMS IN SITU.

DESIGN CONSIDERATIONS FOR SPACE DEBRIS AN INDUSTRY VIEWPOINT

by

Dr. H. W. Babel
McDonnell Douglas Astronautics Company

INTRODUCTION/BACKGROUND ENVIRONMENT & SHIELD CAPABILITY

- **Debris has become much more severe than micrometeoroids**
- **Debris flux below 10 cm based primarily on analytic projections**

INTRODUCTION AND BACKGROUND DEBRIS CONSIDERATIONS

	In-Space	Ground Simulation Facilities
Velocity	1 - 14 km/sec Peak flux around 12 km/sec	To 8 km/sec for 1 cm dia spherical Al particle
Particle shape	Fragments	Spheres and rods
Alloy	Approx. 90% aluminum	Al and to a lesser extent other material
Mass	Estimates only	To 18 gm
Angle of Impact	All	Studied for spherical particles

TECHNOLOGY NEEDS PREVENT LOSS OF SPACECRAFT OR LIFE FROM LARGE PARTICLES

- Large size debris particles (>10 cm)
  - Spacecraft avoidance maneuver
    - Need high accuracy tracking system
    - Need early warning - 2 hours before impact
  - Mitigation concepts
    - Deflect particle orbit, disintegrate, vaporize
    - Sweep out the debris

TECHNOLOGY NEEDS PREVENT LOSS OF SPACECRAFT OR LIFE FOR 1 TO 10 CM PARTICLES

- Medium size debris particles (~ 1 to 10 cm)
  - Validation of flux predictions based on debris measurements
  - Definition of debris particles - shape, alloy, and size
  - Ability to test design concepts under realistic conditions
    - Ground test facilities
    - In-space
  - Lighter weight shield concepts

EXAMPLES OF POSSIBLE IN-SPACE EXPERIMENTS RELATIVE TO DEBRIS

- Debris definition concept
  - Move active debris capture system in debris path - slow down and capture such as done for bullets
  - Develop a large area passive capture system that can be deployed; e. g., multiple pocket capture systems (in concept like a down quilt)
- Debris mitigation
  - Passive large area screens that slow particles as they pass through, so they re-enter quickly. Select screen materials that do not cause secondary ejecta
- Shield evaluation in space
  - Seed projectile(s) and subsequently deploy tethered shield concept to be impacted. Ensure impact and retrieve shield for post test evaluation. Measure relative velocity between particle and shield. Seeded particles to re-enter quickly if experiment aborted.

SPACE DEBRIS ENVIRONMENT DEFINITION

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INTRODUCTION/BACKGROUND

- o Natural Environment - micrometeoroids: constant
- o Artificial Space Debris: increasing
  - Sources and Sinks
  - Trackable and Untrackable
- o Hazards from Untrackable Space Debris
  - Mission Catastrophic
  - Mission Degrading
- o Necessity of Modeling and Simulating Debris

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TECHNOLOGY NEEDS

- o Modeling
  - Current Environment
  - Future Scenarios
- o Simulation
  - Debris Generation and Evolution
  - Specific Hazard Analysis
  - Spacecraft Breakup Models
- o Debris Detection and Verification
- o Model Validation

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MODELING AND SIMULATION

- University of Colorado Debris Models
- NASA Johnson Space Center Analytic Debris Models
- U.S. Air Force Space Command SMART Catalog
  - Extended Catalog
  - Statistical Database for Space Debris
  - Hybrid Database
- Feedback from Debris Sampling
  - Validation of Models
  - Updating of Databases

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IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- o On-Orbit Sampling
  - Quicksat
  - LDEF Retrieval and Analysis
  - Future Sampling
- o Damage-model Validation
  - Breakup Simulation
  - Reconciliation of Results with Other Space Experiments
- o Shielding Testing and Model Validation

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SUMMARY/RECOMMENDATIONS

- o Modeling/Simulation Development
- o Detection/Sampling for Validation and Updating
- o On-Orbit Hazard Verification
- o On-Orbit Shielding Verification

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2.3 CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS

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SPACE ENVIRONMENTAL EFFECTS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CHARGED PARTICLES & ELECTROMAGNETIC RADIATION EFFECTS

EFFECTS OF CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION ON STRUCTURAL MATERIALS AND COATINGS

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BACKGROUND

- HIGH DOSES OF PARTICLE RADIATION DEGRADE MECHANICAL PROPERTIES OF POLYMERIC FILMS, ADHESIVES AND RESIN-MATRIX COMPOSITES
- PRECISION SPACE STRUCTURES REQUIRE LOW CTE, STIFF MATERIALS
- ELECTRON RADIATION WITH THERMAL CYCLING DEGRADES CTE OF POLYMERIC-MATRIX COMPOSITES
- SOLAR UV RADIATION AFFECTS OPTICAL AND MECHANICAL PROPERTIES OF MOST POLYMERIC FILMS AND COATINGS
- DATA NOT AVAILABLE ON LONG-TERM EFFECTS OF RADIATION AND THERMAL CYCLING ON STRUCTURAL MATERIALS AND COATINGS IN SPACE

TECHNOLOGY PROGRAMS

- PRECISION SEGMENTED REFLECTOR (LARGE DEPLOYABLE REFLECTOR)
- SPACE STATION FREEDOM
- SPACE DEFENSE INITIATIVE
- GLOBAL CLIMATE CHANGE PROGRAM
- NASA BASE TECHNOLOGY RESEARCH ON SPACE ENVIRONMENTAL EFFECTS

CURRENT FLIGHT EXPERIMENTS

- LDEF (RETURN LATE 1989)
- EOIM-3
- DELTA STAR

TECHNOLOGY NEEDS

- ABILITY TO PREDICT USEFUL LIFETIMES OF FILMS, COATINGS, ADHESIVES, AND STRUCTURAL MATERIALS IN ANY SPACE SERVICE ENVIRONMENT
- LONG-TERM SYNERGISTIC EFFECTS DATA BASE (UV, e^-, P^+, TEMP. CYCLING)
- ACCELERATED TESTING METHODOLOGY FOR SIMULATION OF REAL-TIME SPACE RADIATION EFFECTS
- STANDARDIZED UV SOURCES AND TEST TECHNIQUES
- MODEL COMPOUNDS TO ELUCIDATE RADIATION EFFECTS FOR DEGRADATION MECHANISM STUDIES
- MATERIALS DESIGNED TO UNDERSTAND EXPOSURE ENVIRONMENT
- MECHANICAL PROPERTY TESTING IN-SPACE WITH RADIATION EXPOSURE

IN-SPACE NEEDS

- RADIATION EFFECTS FLIGHT DATA FOR VERIFICATION OF LABORATORY TESTING AND DEVELOPMENT OF ANALYTICAL MODELS
- RADIATION EFFECTS DATA IN SERVICE ENVIRONMENTS OF GEO, INNER VAN ALLEN BELT, LEO EQUATORIAL AND POLAR
- SPACE RADIATION ENVIRONMENT DATA FOR PROTONS < 10 meV AND ELECTRONS < 1 meV
- MECHANICAL/OPTICAL PROPERTY DATA IN SPACE
- "SMART" MATERIALS WHICH MONITOR IN-SPACE PERFORMANCE
- ADDITIONAL LONG-TERM FLIGHT OPPORTUNITIES

SUMMARY

- PRECISION SPACE STRUCTURES ARE REQUIRED FOR SPACE ANTENNA SYSTEMS AND MOST LARGE SPACE STRUCTURAL APPLICATIONS
- LONG-TERM IN-SPACE DATA NEEDED TO ESTABLISH RADIATION DURABILITY
- LONG-TERM FLIGHTS ALSO NEEDED IN EACH PROPOSED FLIGHT ENVIRONMENT TO PROVIDE:
  - DATA TO IMPROVE ENVIRONMENT MODELS
  - DATA FOR LABORATORY CORRELATION
  - VERIFICATION OF LONG-TERM PERFORMANCE PREDICTIONS FROM SHORT-TERM FLIGHT AND LAB DATA

ENVIRONMENTAL EFFECTS THEME	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS SUBTHEME

CHARGED PARTICLES AND ELECTROMAGNETIC EFFECTS ON SPACE SYSTEMS: TECHNOLOGY REQUIREMENTS FOR THE FUTURE

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INTRODUCTION/BACKGROUND

WHAT WE ARE INTERESTED IN:

- DEFINING LONG TERM RADIATION EFFECTS ON ELECTRONIC SYSTEMS AND SENSORS.
- PLANNING LONG TERM MISSIONS IN HOSTILE RADIATION ENVIRONMENTS.
- PROTECTING AGAINST SINGLE EVENT UPSETS AND DOSAGE EFFECTS.

TECHNOLOGY NEEDS

NEEDS DUE TO NEW TECHNOLOGIES:

- REQUIRE METHODS FOR REDUCING SENSITIVITY TO HIGH-Z/HIGH ENERGY COSMIC RAY AND SOLAR FLARE PARTICLES (I.E., "VOTING", SPECIAL DESIGNS, NEW SHIELDING TECHNOLOGY).
- SENSITIVITY TO LATCHUP, DISPLACEMENT, AND HIGH ENERGY PROTONS MAY BECOME CONCERNS IN FUTURE GENERATIONS OF DEVICES.
- FIBER OPTICS AND OTHER TECHNOLOGIES THAT ARE "HARD" TO SEU'S AND OTHER RADIATION EFFECTS NEED TO BE DEVELOPED FOR SPACE USE.
- NEED TO DEVELOP COMPREHENSIVE TESTING METHODS FOR COMPONENTS (PARTICULARLY FOR SEU EFFECTS AND LONG TERM DOSAGE) THAT CAN SIMULATE IN-SPACE COMPOSITION AND ENERGY SPECTRA.
- REQUIRE COMPUTER MODELLING TOOLS FOR PREDICTING RADIATION EFFECTS ON NEW COMPONENTS.

TECHNOLOGY NEEDS (CONT.)

NEEDS DUE TO EXTENDED MISSIONS:

- NEED NEW TESTING TECHNOLOGIES CAPABLE OF SIMULATING DOSE/RATE, TOTAL DOSE, AND ANNEALING.
- INTERNAL CHARGING OF COMPONENTS OVER LONG TIME PERIODS NEEDS TO BE DEFINED AND ARCING CHARACTERISTICS DEFINED.
- LONG TERM EFFECTS OF INDUCED RADIATION/HEATING ON COMPONENTS NEED TO BE DEFINED.
- UNIFORM TECHNIQUES FOR DEFINING/APPLYING RADIATION DESIGN MARGINS NEED TO BE DEVELOPED.
- NEW TECHNIQUES FOR HARDENING PARTS NEED TO BE DEVELOPED WITH PART EXPOSURES IN EXCESS OF $10^5 - 10^6$ RADS TYPICAL.
- REQUIRE INEXPENSIVE, RELIABLE RADIATION MONITORS CAPABLE OF BEING STANDARD "HOUSEKEEPING" ITEM ON ALL MISSIONS.

TECHNOLOGY NEEDS (CONT.)

NEEDS DUE TO SIZE/PROLIFERATION:

- REQUIRE CHEAP/INTRINSICALLY "HARD" COMPONENTS FOR PROLIFERATION MISSIONS (I.E., PHASED ARRAY RADAR)
- BETTER SHIELDING TECHNIQUES TO REDUCE MASS REQUIREMENTS.
- ACCURATE, USER-FRIENDLY SHIELDING MODELS CAPABLE OF MODELING COMPLEX GEOMETRIES ARE REQUIRED.
- ENVIRONMENTAL IMPACT--LARGE SIZES MAY MODIFY RADIATION AND PARTICULATE ENVIRONMENTS.
- BETTER MODELS OF ENVIRONMENT FOR MISSION PLANNING AND OPERATIONS ARE REQUIRED (SOLAR FLARES, GEOMAGNETIC STORMS, ETC.)

TECHNOLOGY NEEDS (CONT.)

NEEDS DUE TO NEW ENVIRONMENTS:

- DEVICES REQUIRED TO SURVIVE NEAR NUCLEAR REACTORS (SP-100) WILL NEED TO WITHSTAND DOSAGES IN EXCESS OF $10^6 - 10^7$ RADS.
- INCREASING UTILIZATION OF THE 1000-30000 KM ALTITUDE RANGE WILL REQUIRE MUCH MORE RADIATION-INSENSITIVE DEVICES. BOTH DOSE/RATE AND DOSAGE EFFECTS WILL BE OF CONCERN.
- LONG TERM MISSIONS IN INTERPLANETARY AND INTERSTELLAR SPACE WILL REQUIRE SELF-ANNEALING PARTS.
- DOD-UNIQUE REQUIREMENTS FOR SURVIVABILITY (I.E., MICROWAVE ENVIRONMENTS, NUCLEAR WEAPONS) NEED TO BE INCLUDED.
- NEW, UNEXPECTED EFFECTS ARE LIKELY! TECHNIQUES FOR IDENTIFYING AND FOR RAPIDLY COPING WITH THESE ARE REQUIRED.

SUMMARY/RECOMMENDATIONS

SPACE RADIATION EFFECTS:

- RADIATION EFFECTS ON SYSTEMS WILL BE A CONTINUING AND POTENTIALLY GROWING CONCERN IN THE DECADES AHEAD. NEW, MORE STRINGENT MISSION RADIATION REQUIREMENTS ARE INEVITABLE.

- A CONSISTENT, LONG RANGE POLICY OF MONITORING THE ENVIRONMENT AND EVALUATING NEW TECHNOLOGIES IS CRUCIAL TO CONTROLLING THE IMPACT OF RADIATION.

- INCREASES IN HARDENING AND REDUCTIONS IN SHIELDING MASS REQUIREMENTS ARE THE KEYS TO SUBSTANTIAL MISSION ENHANCEMENT.

- GROUND TEST, MODELLING (ENVIRONMENT AND INTERACTION), DEVELOPMENT OF DESIGN GUIDELINES, AND IN SITU EXPERIMENTATION MUST GO HAND-IN-HAND.

KEY EXPERIMENTS

SPACE RADIATION EFFECTS:

- COMPREHENSIVE ELECTRONIC COMPONENT TESTING FACILITY
- FLARE/STORM PREDICTION CAPABILITY
- STANDARDIZED ENVIRONMENTAL MONITORING PACKAGES
- IN-SPACE RADIATION TESTING FACILITY

ELECTROMAGNETIC AND PLASMA ENVIRONMENT INTERACTIONS: TECHNOLOGY NEEDS FOR THE FUTURE

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INTRODUCTION/BACKGROUND

- MISSIONS OF THE FUTURE REQUIRE TECHNOLOGICAL ADVANCES IN ELECTROMAGNETICS AND SPACE ENVIRONMENT INTERACTIONS.

- THE DRIVERS FOR THESE NEW TECHNOLOGIES ARE THREE FOLD:

  1. INCREASED DURATION AND RELIABILITY REQUIREMENTS;
  2. INCREASED COMPLEXITY OF PAYLOADS AND SUBSYSTEMS;
  3. INCREASED SUSCEPTIBILITY OF COMPLEX SENSORS AND SUBSYSTEMS.

- THESE FACTORS ARE COMPLICATED BY THE NEED FOR INCREASED POWER LEVELS, PROVISION FOR ON-ORBIT INTEGRATION/RECONFIGURATION, AND USE OF ROBOTIC SERVICERS.

MISSION APPLICATIONS

- SPACE STATION ATTACHED PAYLOAD AND RACKS MUST BE INTEGRATED ON ORBIT.
- SYSTEMS WILL BE FLOWN THAT ARE TOO LARGE TO TEST BY MIL-STD 461 METHODS AND WILL NOT FIT IN SCREEN ROOMS OR TEST CHAMBERS.
- LARGE STRUCTURES SUCH AS ACTIVE ELEMENT PHASED ARRAYS REQUIRE SPECIAL CONSIDERATION FOR ESD AND EM COMPATIBILITY.
- MATERIALS THAT SERVE TO PROTECT A SYSTEM CHANGE WITH AGE (UV, RADIATION, SURFACE CONTAMINATION, OXYGEN EROSION, DEBRIS IMPACT)
- NEW GENERATION SENSORS AND INSTRUMENTS NEED HIGH DENSITY ELECTRONICS, HIGH CLOCK FREQUENCIES, AND LOW BACKGROUND NOISE.
- HIGH POWER SYSTEMS AND THEIR DISTRIBUTION ARCHITECTURES MUST CONSIDER EMI AND PLASMA EFFECTS FROM INCEPTION.

TECHNOLOGY NEEDS

- THE NEEDS WILL BE FOCUSED ON THREE AREAS: <u>EMI/EMC TECHNOLOGY</u>; <u>PLASMA/NEUTRAL INTERACTIONS</u>; <u>SENSOR DEVELOPMENT</u>.

- THE EMI/EMC TECHNOLOGY NEEDS ARE DRIVEN BY SYSTEM AND OPERATIONAL REQUIREMENTS

  1. EM ENVIRONMENT MUST INCLUDE INTERACTION WITH THE PLASMA
  2. ESD DESIGN MUST BE COMPATIBLE WITH THERMAL REQUIREMENTS AND WEIGHT LIMITATIONS.
  3. SOFTWARE VERIFIED AS NON-SUSCEPTIBLE TO EMI
  4. METHODS OF DIAGNOSING AND SOLVING EMC PROBLEMS ON ORBIT

- PLASMA INTERACTIONS DESCRIBE INTERRELATIONSHIP BETWEEN THE PLASMA ENVIRONMENT (LEO,GE0,INTERPLANETARY) AND THE SYSTEM

TECHNOLOGY NEEDS (CONT.)

- ISSUES THAT NEED RESOLUTION IN ORDER TO ACCURATELY PREDICT THE CONSEQUENCES OF CERTAIN ENVIRONMENT/SYSTEM COMBINATIONS.

  1. PLASMA CHEMISTRY WITH CONTAMINANT EFFLUENTS
  2. CHARACTERIZATION OF MATERIALS (PHOTO EMISSION, SECONDARY PRODUCTION, ION SPUTTERING ETC.)
  3. CONTROL OF CHARGE BUILDUP ON LARGE SURFACES
  4. MODEL OF COMBINED NEUTRAL/PLASMA ENVIRONMENTS NEAR LARGE OBJECTS
  5. BREAKDOWN THRESHOLDS, DISCHARGE CURRENTS AS FUNCTION OF GEOMETRY, MATERIAL, AND PLASMA DENSITY.

- TO BETTER UNDERSTAND AND MODEL THE ENVIRONMENT EFFECTS AND EMI, NEW SENSOR TECHNOLOGY MUST BE DEVELOPED.

  1. SFR'S AND OTHER FLIGHT QUALIFIED, LIGHT WEIGHT DIAGNOSTIC EQUIPMENT
  2. ION/NEUTRAL MASS SPECTRAL ANALYSIS WITH TRACE ELEMENT SENSITIVITY
  3. DISTRIBUTED SENSORS AS STANDARD COMPONENTS OF LARGE SYSTEMS
  4. MEASUREMENT OF DISTRIBUTION FUNCTION OF PARTICULATE MATERIALS

EXPERIMENTATION NEEDS

- <u>GROUND BASED EXPERIMENTS/STANDARDS/MODELS</u>

- EMI/EMC:

  1. TOOLS FOR SIMULATING ON-BOARD PERFORMANCE BASED ON GROUND TESTS.
  2. LONG-LIFE MATERIALS WITH GOOD CONDUCTIVITY/THERMAL PROPERTIES
  3. TOOLS FOR VERIFYING SOFTWARE RELIABILITY IN EM ENVIRONMENT

- PLASMA INTERACTIONS

  1. CROSS SECTIONS FOR CHEMICAL REACTIONS BETWEEN AMBIENT AND CONTAMINANTS
  2. PREDICT ARC THRESHOLD WITH ACTIVE AND PASSIVE DEVICES AS FUNCTION OF GEOMETRY, MATERIAL, AND PLASMA DENSITY

- SENSORS

  1. CONVERT LABORATORY SENSORS TO SPACE ENVIRONMENT
  2. DEVELOP TECHNIQUES FOR MORE SENSITIVE SPECTROMETRY

EXPERIMENT NEEDS--FLIGHT

- EMI/EMC:
  1. FLIGHT TEST NEW CONDUCTIVITY COATINGS (LONGEVITY)
  2. VERIFY GROUND MEASUREMENTS OF ARCS

- PLASMA/INTERACTIONS
  1. MEASURE DYNAMICS OF PLASMA AND NEUTRAL GAS CLOUDS TO VERIFY AND IMPROVE MODELS
  2. CHARGING OF LARGE STRUCTURES IN WAKE AND IN POLAR ORBIT

- SENSORS
  1. INVESTIGATE USE OF SUPERCONDUCTING TECHNOLOGY IN SENSORS
  2. DEVELOPMENT OF SMALL, AUTONOMOUS DISTRIBUTED SENSORS.

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SPACE ENVIRONMENTAL EFFECTS CRITICAL TECHNOLOGY REQUIREMENTS

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NASA/SDI MEETING ON SPACE ENVIRONMENTAL EFFECTS

- MEETING HELD DURING MID 1988 TO REVIEW TECHNOLOGY NEEDS FOR SPACE ENVIRONMENTAL EFFECTS

- RESULTS OF MEETING EMPHASIZED THE FOLLOWING:
  - SUBJECT FOR ONGOING EXPERIMENTS
    - LDEF
    - EOIM III
    - OTHER MISSIONS SUCH AS DELTA STAR
  - NEED FOR SIMULATION FACILITIES
  - NEED FOR FUTURE EXPERIMENT CARRIERS FOR EXTENSIVE STUDY OF EFFECTS

- IN-STEP MEETING WAS THEREFORE FOCUSED MORE DIRECTLY TO IN-SPACE EXPERIMENT NEEDS THAT WOULD BE THE SUBJECT OF THE NEXT OUT-REACH SOLICITATION

MISSION RELATIONSHIP

- FUTURE NATIONAL SPACE MISSIONS ARE MORE COMPLEX, REQUIRE LONG LIFE AND UTILIZE MORE SENSITIVE INSTRUMENTATION
- INFORMATION GAINED OVER THE LAST DECADE HAS IDENTIFIED ASPECTS OF THE ENVIRONMENT WHICH COULD BE LIFE LIMITING TO LARGE SPACECRAFT
- DEBRIS - IMPACT BY 30 CM SIZE OBJECT IN 30 YEARS
- ATOMIC OXYGEN - COMPLETE REMOVAL BY EROSION OF SPACE STATION UNCOATED STRUCTURAL TUBES IN 15 YEARS
- SUCCESSFUL ACCOMPLISHMENT OF FUTURE MISSIONS REQUIRES IN CREASED EMPHASIS ON ENVIRONMENTAL EFFECTS
- LONG LIFE ENHANCES ENVIRONMENTAL EFFECTS
- NEW UNDERSTANDING OF ENVIRONMENT AND EFFECTS ON SPACECRAFT

WHY IN-SPACE EXPERIMENTS?

- WELL CHARACTERIZED ENVIRONMENT NECESSARY TO SUPPORT PROPER DESIGN OF FUTURE MISSIONS - THEME ENCOURAGES BROAD BASE MEASUREMENTS

- ENVIRONMENT SIMULATION DIFFICULT

    - NOT POSSIBLE TO SIMULATE MANY ASPECTS OF THE ENVIRONMENT - ENERGY, COMPOSITION

    - INTERACTION OF THE ENVIRONMENT WITH SURFACES IS SENSITIVE TO MANY PARAMETERS WHICH ARE HARD TO CONTROL

    - NEED IN-SPACE DATA TO VERIFY GROUND BASED SIMULATION SYSTEMS

ATMOSPHERIC EFFECTS AND CONTAMINATION SUMMARY

To develop materials and material configurations which are environmentally durable and functionally compatible with long duration space missions, it is necessary to perform in-space experiments to quantify and characterize interactions with the atmospheric and space system environment. This data will provide for an understanding of mechanisms involved and enable the development of ground based modeling and simulation technologies needed for materials and material applications development.

Critical technology needs identified include: active measurement of atomic oxygen flux for accurate real time data on all atmospheric interaction phenomena; glow phenomena information for compatible sensor design; contamination effects and atomic oxygen erosion data (direct and scattered reactions) for durability and functional performance prediction; contamination effects data and abatement techniques for long term space system durability and spacecraft/atmosphere interaction.

ATMOSPHERIC EFFECTS AND CONTAMINATION SUMMARY

PRIORITY	AVERAGE SCORE	IN-SPACE TECHNOLOGY NEED
1	1.3	Active Measurement of A/O flux
2	1.7	Glow - LEO
2	1.7	Data to enable ground based modeling and simulation
3.	1.9	Materials Erosion
4	2.0	Contamination - All Altitudes
4	2.0	Demonstration of Contamination abatement/reduction techniques
5	2.1	Drag - Low Earth Orbit
5	2.1	Measurements of Contamination generation/transport/effects (all phases) for improved model.
6	2.7	Contamination Design guidelines Experiments
6	2.7	Measurements of perturbations to the ambient environment due to spacecraft/ atmospheric interactions.

MICROMETEOROIDS AND DEBRIS SUMMARY

- CHARACTERIZATION OF THE LEO DEBRIS ENVIRONMENT AND ITS EFFECT ON SPACECRAFT
  - LEO ENVIRONMENT PARTICLE SIZE DISTRIBUTION, SPECTRAL PROPERTIES CHARACTERIZATION
  - LONG TERM SURFACED DEGRADATION FROM DEBRIS
  - IN-SPACE SAMPLING OF COLLISION FRAGMENTS: SIZE, SHAPE AND COMPOSITION
- IN-SPACE TESTING OF PROTECTION AND MITIGATION TECHNIQUES FROM LEO DEBRIS
  - DEVELOPMENT AND VERIFICATION OF COLLISION WARNING SYSTEMS TECHNOLOGY IN-SITU
  - EVALUATION OF SHIELD CONCEPTS IN-SITU
  - EVALUATION AND VERIFICATION OF MITIGATION TECHNIQUES IN-SITU

MICROMETEOROIDS AND DEBRIS SUMMARY

PRIORITY	AVERAGE SCORE	IN-SPACE TECHNOLOGY NEED
1	1.14	LEO PARTICLE DISTRIBUTION
2	2.27	COLLISION WARNING SYSTEM
3	2.29	IN-SPACE DEBRIS SAMPLING
4	2.44	IN-SITU SHIELD EVALUATION
5	2.80	SURFACE DEGRADATION
6	3.00	MITIGATION TECHNIQUES
7	3.29	EXTERNAL TANK USE

CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS SUMMARY

- MONITORING OF RADIATION ENVIRONMENT EFFECTS ON MATERIALS AND ICs
  - NEED LONG TERM, CONTINUOUS MEASUREMENTS OF MECHANICAL, OPTICAL, AND ELECTRICAL PROPERTIES IN CRITICAL ORBITS (LEO, GEO, POLAR)
  - NEED DATA TO VALIDATE GROUND TESTING TECHNIQUES
  - NEED DATA TO UPGRADE/VALIDATE RADIATION AND SOLAR FLARE MODELS
- NEED TO DETERMINE EFFECTS OF CHEMICAL VENTING IN LEO ON ELECTROMAGNETIC INTERFERENCE AND SURFACE DEPOSITION
- DEVELOP AND TEST IN SPACE SIMPLE, SMALL AUTONOMOUS SENSORS FOR SURFACE CHARGING, RADIATION EXPOSURE AND ELECTRIC FIELDS

CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS SUMMARY

PRIORITY	AVERAGE SCORE	IN-SPACE TECHNOLOGY NEED
1	1.7	MONITOR IN-SITU ENVIRONMENT ON CONTINUING BASIS.
2	1.8	VALIDATE GROUND TEST TECHNIQUES USING IN-SPACE EXPERIMENTS.
3	1.87	LONG-TERM IN-SPACE DATA IN PROPOSED ORBITAL ENVIRONMENTS.
4	1.91	MECHANICAL / OPTICAL PROPERTIES MEASURED IN SPACE IN A VARIETY OF ORBITS.
5	2.0	DETERMINE ELECTROMAGNETIC AND DEPOSITION CONSEQUENCES FROM THE VENTING OF EXPECTED CHEMICALS IN THE LOW EARTH ORBIT ENVIRONMENT.
5	2.0	DATA TO UPGRADE / VALIDATE RADIATION & SOLAR FLARE MODELS.
6	2.22	DEVELOP AND TEST SIMPLE, SMALL AUTONOMOUS SENSORS FOR SURFACE CHARGING, RADIATION EXPOSURE AND ELECTRIC FIELD.

CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS SUMMARY

(Cont.)

PRIORITY	AVERAGE SCORE	IN-SPACE TECHNOLOGY NEED
7	2.44	UNDERSTAND THE MATERIAL / PLASMA INTERFACE BY TESTING LONG-TERM CONDUCTIVITY OF DIELECTRICS AND EFFECTIVENESS OF CONDUCTIVE COATINGS.
7	2.44	DETERMINE ARC ONSET VOLTAGES OF EXPECTED DIELECTRIC / METAL GEOMETRIES AND TEST DISCHARGE EMI IN LOW EARTH ORBIT CONDITIONS
8	2.45	"SMART" MATERIALS WHICH HELP CORRELATE FLIGHT DATA TO LABORATORY DATA.
9	2.6	VALIDATE SEU MODELS WITH IN-SPACE TESTS
9	2.6	DEVELOP PERMANENT IN-SPACE RADIATION TESTING FACILITY. SHOULD BE IN WORST PART OF RADIATION BELTS.
10	2.9	QUANTIFY INTERNAL CHARGING EFFECTS ON COMPONENTS.
11	3.1	TEST FIBER OPTICS SYSTEMS BEHAVIOR UNDER LONG-TERM EXPOSURE

3. POWER SYSTEMS AND THERMAL MANAGEMENT

POWER SYSTEMS AND THERMAL MANAGEMENT BACKGROUND AND OBJECTIVES

ROY McINTOSH
GODDARD SPACE FLIGHT CENTER

SUMMARY OF THE NASA/OAST SPONSORED

IN-SPACE RESEARCH, TECHNOLOGY AND ENGINEERING (RT&E) WORKSHOP

HELD AT:

WILLIAMSBURG, VA   8-10 OCTOBER, 1985

-WORKSHOP BACKGROUND-

- ADVENT OF THE SPACE STATION MARKS A NEW ERA OF PERMANENTLY MANNED PRESENCE IN SPACE
- EXISTING TECHNOLOGY BASE NEEDED EXPANSION IN SEVERAL KEY AREAS
- INDUSTRY AND UNIVERSITY INVOLVEMENT IN SPACE ACTIVITIES ANTICIPATED TO INCREASE
- PERCEIVED NEED TO BRING TOGETHER INDUSTRY,UNIVERSITY, AND GOVERNMENT RESEARCHERS IN A COMMON FORUM

-WORKSHOP GOALS-

- IDENTIFY FUTURE NEEDS FOR IN-SPACE EXPERIMENTS IN SUPPORT OF SPACE TECHNOLOGY DEVELOPMENT, ESPECIALLY AS RELATED TO THE SPACE STATION
- VALIDATE NASA'S IN-SPACE EXPERIMENT THEME AREAS
- INITIATE A LONG-TERM PROGRAM OF OUTREACH TO UNIVERSITIES AND PRIVATE INDUSTRY TO ESTABLISH A USER COMMUNITY NETWORK
- FORM THE BASIS FOR ESTABLISHMENT OF ON-GOING TECHNICAL WORKING GROUPS

-WORKSHOP GOALS-

- IDENTIFY FUTURE NEEDS FOR IN-SPACE EXPERIMENTS IN SUPPORT OF SPACE TECHNOLOGY DEVELOPMENT, ESPECIALLY AS RELATED TO THE SPACE STATION
- VALIDATE NASA'S IN-SPACE EXPERIMENT THEME AREAS
- INITIATE A LONG-TERM PROGRAM OF OUTREAC TO UNIVERSITIES AND PRIVATE INDUSTRY TO ESTABLISH A USER COMMUNITY NETWORK
- FORM THE BASIS FOR ESTABLISHMENT OF ON-GOING TECHNICAL WORKING GROUPS

-WORKSHOP THEME AREAS-

- SPACE STRUCTURES (DYNAMICS & CONTROL)
- FLUID MANAGEMENT
- SPACE ENVIRONMENTAL EFFECTS
- ENERGY SYSTEMS & THERMAL MANAGEMENT
- INFORMATION SYSTEMS
- AUTOMATION & ROBOTICS
- IN-SPACE OPERATIONS

ENERGY SYSTEMS AND THERMAL MANAGEMENT

KEY TECHNOLOGY ISSUES

FUNDAMENTAL PHENOMENA

- o THERMAL TRANSPORT
  - PHASE CHANGE SYSTEMS
- o THERMAL STORAGE
  - SOLID/LIQUID CONTAINMENT
  - HEAT FLOW MANAGEMENT

ENVIRONMENTAL FACTORS

- o ATOMIC OXYGEN
- o SPACE PLASMA
- o MICROMETEOROIDS

PERFORMANCE TESTING

- o COMPONENTS/SUBSYSTEM
- o SYSTEMS

-WORKSHOP RESULTS-

KEY TECHNOLOGY ISSUES

- FUNDAMENTAL PHENOMENA
  - -HEAT TRANSFER IN MICRO-GRAVITY
  - -PHASE CHANGE/THERMAL STORAGE
- ENVIROMENTAL CONCERNS
  - -MICROMETEROIDS, ATOMIC OXYGEN, SPACE PLASMA
- PERFORMANCE TESTING (IN-SPACE)
  - -TWO-PHASE COMPONENTS AND SUBSYSTEMS
  - -TWO-PHASE SYSTEMS

ENERGY SYSTEMS AND THERMAL MANAGEMENT

GENERAL OBSERVATIONS

- MUCH OF PROPOSED EXPERIMENTAL EFFORT COULD BE CONDUCTED ON THE GROUND
- MANY PROPOSED EXPERIMENTS WERE APPROPRIATE FOR PRECURSOR SHUTTLE FLIGHT
- SOME EXPERIMENTS WERE NOT SUITED FOR SHUTTLE OR SPACE STATION
- MOST EXPERIMENTS WERE AT THE "IDEA" LEVEL -- MINIMAL TECHNICAL DETAIL
- TWO FUNDAMENTAL RESEARCH AREAS WERE IDENTIFIED AS REQUIRING SPACE FLIGHT
    - PHASE CHANGE/HEAT TRANSFER PHENOMENA IN ZERO-G
    - ENVIRONMENTAL EFFECTS
- ADVANCED POWER AND THERMAL SYSTEMS WILL REQUIRE IN-SPACE EXPERIMENTAL SUPPORT

-WORKSHOP RESULTS-

FUTURE ACTIVITIES

- 1986: ANNOUNCEMENT OF OPPORTUNITY FOR IN-SPACE EXPERIMENTS
  - -231 PROPOSALS RECEIVED
  - -41 PROPOSALS SELECTED, MOSTLY FOR DEFINITION PHASE EFFORT
- 1988: NASA/OAST WORKSHOP ON TWO-PHASE FLUID BEHAVIOR IN A SPACE ENVIRONMENT
- 1988: IN-STEP 88 WORKSHOP

SUMMARY OF THE NASA/OAST SPONSORED

WORKSHOP ON TWO-PHASE FLUID BEHAVIOR IN A SPACE ENVIRONMENT

HELD AT:

OCEAN CITY, MARYLAND 13–14 JUNE, 1988

-GENESIS OF WORKSHOP-

* NASA HQ RECEIVED A LARGE NUMBER OF PROPOSALS WHICH FOCUSED ON RESEARCH INTO TWO-PHASE FLOW PHENOMENA IN A MICROGRAVITY ENVIRONMENT. THIS SPOTLIGHTED THE PROBLEM.

* COST AND MANIFESTING CONSTRAINTS PROHIBIT MORE THAN A FEW SELECT FLIGHT EXPERIMENTS.

* CONCEPT OF A COORDINATED FLIGHT TEST PROGRAM DEVELOPED.

* HEADQUARTERS REQUESTED GSFC TO ORGANIZE AND CONDUCT A WORKSHOP TO BEGIN PLANNING FOR THIS TEST PROGRAM.

-WORKSHOP GOALS-

* IDENTIFY AND CATEGORIZE/PRIORITIZE THE TECHNICAL ISSUES, CONCERNS, AND PROBLEMS INVOLVED IN DESIGNING TWO-PHASE THERMO-FLUID DYNAMIC SYSTEMS FOR SPACE APPLICATIONS.

* CONCEPTUALIZE POSSIBLE TECHNOLOGIES AND FLIGHT EXPERIMENTS TO ADDRESS THE ISSUES IDENTIFIED.

THE ABOVE WILL PROVIDE THE PRIMARY INPUTS TOWARDS DEFINITION OF THE TEST PROGRAM. WORKSHOP ITSELF DOES NOT SEEK TO DEFINE TEST PROGRAM.

-WORKSHOP RESULTS-
MAJOR TECHNICAL ISSUES

HARDWARE NEEDS;

* HEAT PUMPS
* LOW WEIGHT RADIATORS
* ADVANCED HEAT PIPES
  - CRYOGENIC
  - UPPER MID-TEMPERATURE (e.g. WATER)
  - HIGH TEMPERATURE
* IMPROVED MATERIALS
* STABILITY ENHANCEMENT DEVICES
* HIGH FLUX EVAPORATORS
* VAPOR SEPARATORS

-WORKSHOP RESULTS-

MAJOR TECHNICAL ISSUES

BASIC RESEARCH NEEDS;

* TWO-PHASE INSTABILITIES
* PROPERTIES OF MATERIALS
* ANALYTICAL MODELS
* EMPIRICAL MODELS FOR DESIGN PURPOSES

IN STEP 88 WORKSHOP
OBJECTIVES

- REVIEW STATE OF TECHNOLOGY READINESS IN

  CONVENTIONAL POWER SYSTEMS
  NUCLEAR AND DYNAMIC POWER SYSTEMS
  THERMAL MANAGEMEN

- IDENTIFY CRITICAL TECHNOLOGY NEEDS FOR IN SPACE EXPERIMENTS

  GOVERNMENT
  INDUSTRY
  UNIVERSITY
  AUDIENCE

- PRIORITIZE NEEDS

3.1 DYNAMIC AND NUCLEAR POWER SYSTEMS

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DYNAMIC AND NUCLEAR SYSTEMS

DR. JOHN M. SMITH

POWER SYSTEMS INTEGRATION OFFICE MANAGER

NASA-LEWIS RESEARCH CENTER
CLEVELAND, OHIO

INTRODUCTION AND BACKGROUND

- **PAST EXPERIENCE**
  - NERVA/ROVER
  - SNAP 10A
  - NUCLEAR/THERMIONICS
  - SPACE RANKINE AND BRAYTON
  - SOLAR DYNAMIC CONCENTRATOR AND RECEIVER
  - RTG - 22 U.S. SPACECRAFT
- **PRESENT**
  - GPHS RTG
    - GALILEO
    - ULYSSES

INTRODUCTION AND BACKGROUND

(CONTINUED)

- FUTURE
  - MOD RTG
  - DIPS
  - SOLARDYNAMICS
  - SP-100 THERMOELECTRICS
  - SP-100 STIRLING
  - NUCLEAR/THERMIONICS
- DREAMS
  - NUCLEAR FUSION
  - ANTI-MATTER
  - ETC.

MISSION APPLICATIONS

- EARTH OBSERVING MISSIONS
- MATERIALS PROCESSING PLATFORMS
- SPACE BASED AIR/OCEAN TRAFFIC CONTROL RADAR
- PRODUCTION, MANAGEMENT, STORAGE OF CRYO FLUIDS
- GEO COMMUNICATIONS PLATFORM
- MARS AND/OR PHOBOS SAMPLE ACQUISITION, ANALYSIS, RETURN
- PLANETARY ROVERS (PILOTED AND ROBOTIC)
- LUNAR AND ASTEROID RESOURCE UTILIZATION
- SPACE TRANSFER VEHICLE (NEP AND SEP)
- LUNAR OUTPOSTS TO EARLY MARS OUTPOSTS
- FAR OUTER PLANET ORBITER
- INTERPLANETARY TRAVEL

TECHNOLOGY NEEDS:

- **NUCLEAR**
  - HIGH POWER/ENERGY
  - LONG LIFE/HIGH RELIABILITY
  - AUTONOMOUS OPERATION
  - 100% SAFE
- **DYNAMIC POWER CONVERSION SYSTEMS**
  - 2 PHASE FLOW - RANKINE
  - START-UP/SHUT DOWN/RESTART - RANKINE
  - GAS BEARINGS - BRAYTON AND STIRLING
  - COMPACT/LIGHTWEIGHT RADIATORS

TECHNOLOGY NEEDS: (CONTINUED)

- **SOLAR DYNAMIC SYSTEMS**
  - LIGHTWEIGHT, HIGH HEAT CAPACITY, HIGH THERMAL CONDUCTIVITY THERMAL ENERGY STORAGE (TES) SYSTEMS
  - SPACE VERIFICATION OF TES VOID THEORY AND GROUND EXPERIMENTS
  - THERMAL CONTROL AND ENVIRONMENTAL PROTECTION COATINGS FOR CONCENTRATOR SURFACES
- **POWER MANAGEMENT AND DISTRIBUTION**
  - HIGH POWER/VOLTAGE
  - HIGH TEMPERATURE
  - RADIATION RESISTANT
  - FAULT TOLERANT/AUTONOMOUS
- **MATERIALS**
  - TESTING IN COMBINED SPACE ENVIROINMENT
  - SURFACE COATINGS/MODIFICATION FOR HIGH EMISSIVITY RADIATORS
  - REFRACTORY METAL DATA BASE FOR HIGH TEMPERATURE DYNAMIC AND NUCLEAR SYSTEMS

SUMMARY AND RECOMMENDATIONS

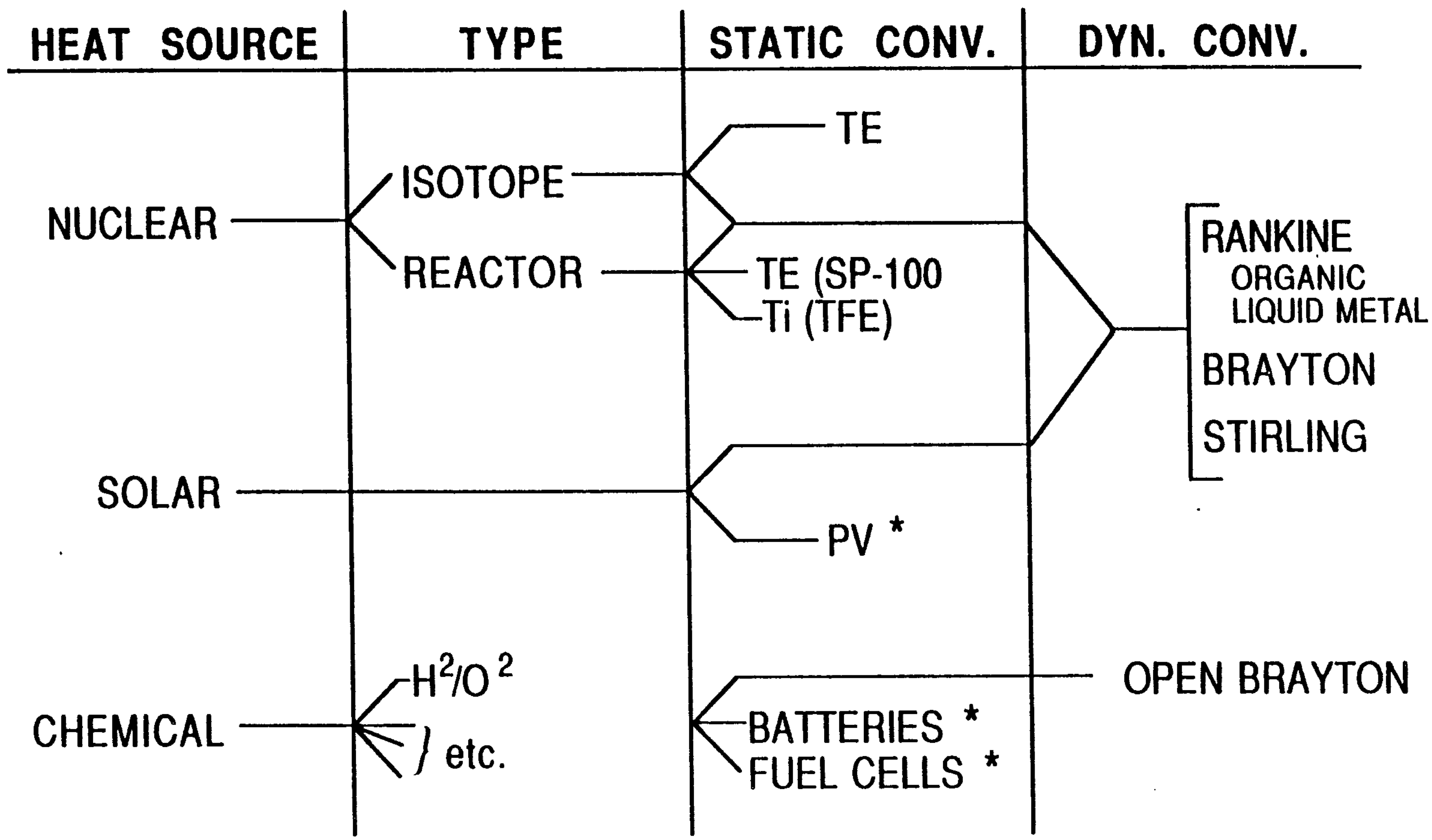
- **DYNAMIC AND NUCLEAR SYSTEMS REQUIRE IN-SPACE EXPERIMENTS**

  BASIC RESEARCH TO PROVIDE DESIGN DATA

  COMPONENT TESTING TO VERIFY DESIGN DATA

- **IN-SPACE EXPERIMENTS PROVIDE ONLY TRUE TEST OF COMBINED SPACE ENVIRONMENTAL EFFECTS**

DYNAMIC AND NUCLEAR SPACE POWER SYSTEMS



* NOT CONSIDERED AS PART OF DYNAMIC AND NUCLEAR SYSTEM WORKSHOP

DYNAMIC & NUCLEAR POWER SYSTEMS

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PROGRAM GENERAL MANAGER
SP-100 PROGRAMS
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TECHNOLOGY NEEDS

- <u>REACTORS</u>
  - HIGH TEMP. TRANSIENT FUEL FOR BURST POWER & PROPULSION
  - WELL CHARACTERIZED HIGH TEMP./STRENGTH MATERIALS
  - MATERIAL FABRICATION & JOINING
- <u>SHEILDING</u>
  - LOW MASS SHIELD MATERIAL/CONFIGURATIONS
  - TEMPERATURE TOLERANT SHIELD MATERIALS
  - IMPROVED MCNP CODES/EXPERIMENT VALIDATION
- <u>CONVERSION</u>
  - IMPROVED PERFORMANCE PASSIVE CONVERSION
  - RELIABLE SPACE QUALIFIED DYNAMIC CONVERSION
  - HIGH TEMP. MATERIALS, BEARINGS/SEALS
  - SPACECRAFT COMPATIBLE - JITTER, EFFLUENTS, ETC.
- <u>STRUCTURE</u>
  - FABRICATION & JOINING IN MICRO/ZERO GRAVITY

TECHNOLOGY NEEDS (CON'T)

- <u>THERMAL MANAGEMENT</u>
  - LOW MASS RADIATORS
  - THERMAL COATINGS
  - LOW MASS SURVIVABILITY TECHNIQUES
  - FAULT TOLERANT - SELF HEALING STRUCTURES
  - LOW COST/HIGH PERFORMANCE HEAT PIPES

- <u>INSTRUMENTATION & CONTROL</u>
  - SUPER RAD HARD ELECTRONICS (INSTR. & COMMUNICATIONS)
  - RELIABLE FAULT TOLERANT ARCHITECTURE
  - HYBRID PACKAGING VLSI COMPONENTS
  - LONG LIFE HIGH TEMP/RAD TOLERANT SENSORS

- <u>POWER MANAGEMENT & DISTRIBUTION</u>
  - HIGH PERFORMANCE, LOW MASS HARDWARE
  - HIGH VOLTAGE TRANSFORMATION, INSULATION & DISTRIBUTION

IN-SPACE EXPERIMENTS

APPLICATION	EXPERIMENT	TIME FRAME
REACTOR COOLANT LOOP	• He GAS COLLECTION AND RETENTION IN LIQUID METAL COOLANTS IN MICRO AND ZERO GRAVITY	'92+
REACTOR COOLANT LOOP CONVERSION	• TWO PHASE SOLID/LIQUID PUMPING, FLOW AND SEPARATION AND MICRO ZERO GRAVITY	'92+
REACTOR COOLANT LOOP CONVERSION	• TWO PHASE LIQUID/GAS SEPARATION AND GAS ACCUMULATION IN WORKING FLUIDS AND COOLANT LOOPS	'92+
REACTOR COOLANT LOOP	• GAS BUBBLE NUCLEATION AND GROWTH PHENOMENA IN LIQUID METALS	'92+

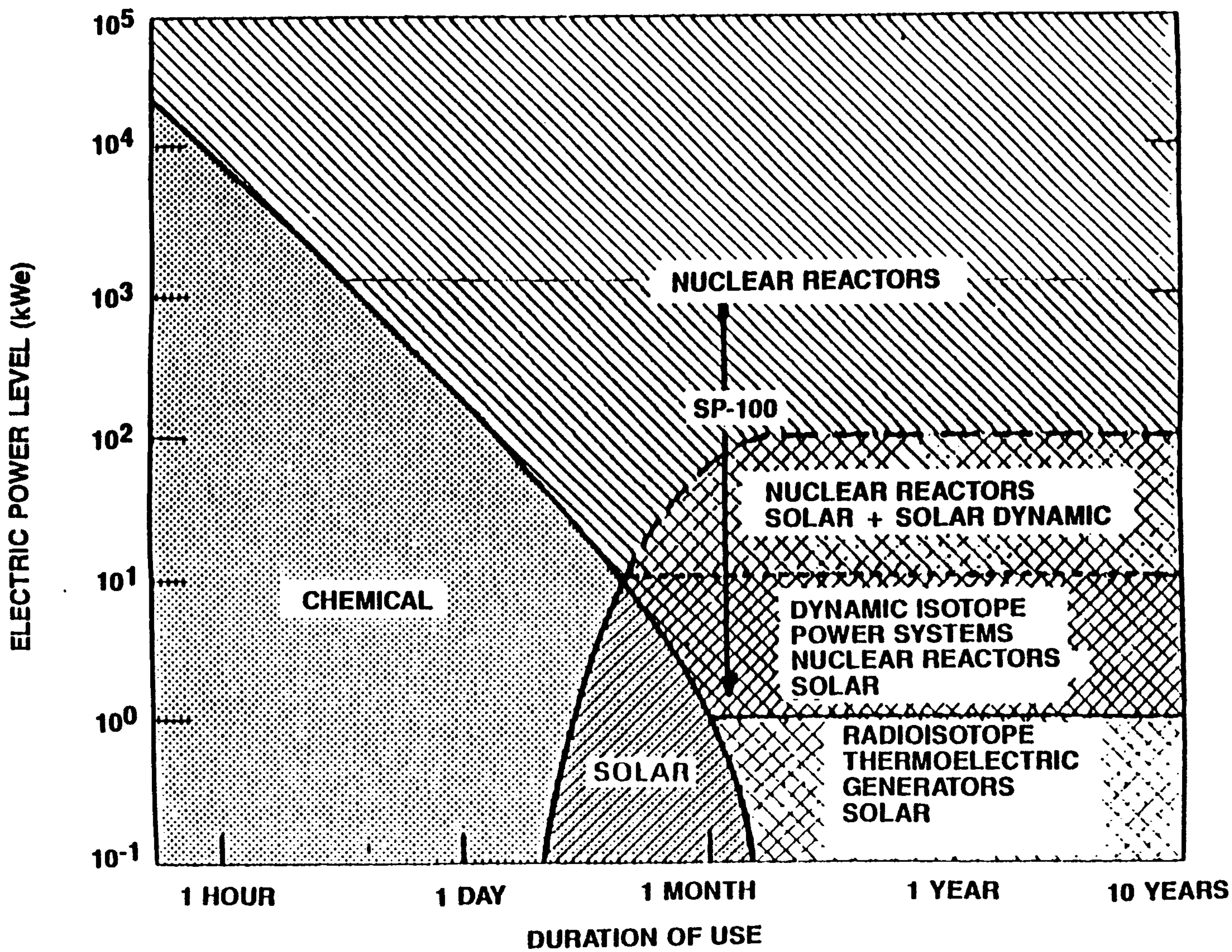
IN-SPACE EXPERIMENTS (CON'T)

APPLICATION	EXPERIMENT	TIME FRAME
REACTOR COOLANT LOOP CONVERSION	• FREEZE/THAW OF LIQUID METALS IN-SPACE, INCLUDING VOID FORMATION AND DISTRIBUTION	'92+
STRUCTURE MATERIALS	• ATOMIC OXYGEN CORROSION RATES OF HIGH TEMP STRUCTURAL MATERIALS IN SPACE ENVIRONMENT	'92+
STRUCTURE MATERIALS FABRICATION OPERATIONS	• MICRO GRAVITY/ZERO GRAVITY EFFECTS ON WELDING AND JOINING	'94+
OPERATIONS	• MAINTENANCE & SERVICING OF POWER SYSTEMS BY ROBOTICS IN REMOTE MICRO-ZERO GRAVITY SPACE & PLANETARY ENVIRONMENTS	'94+

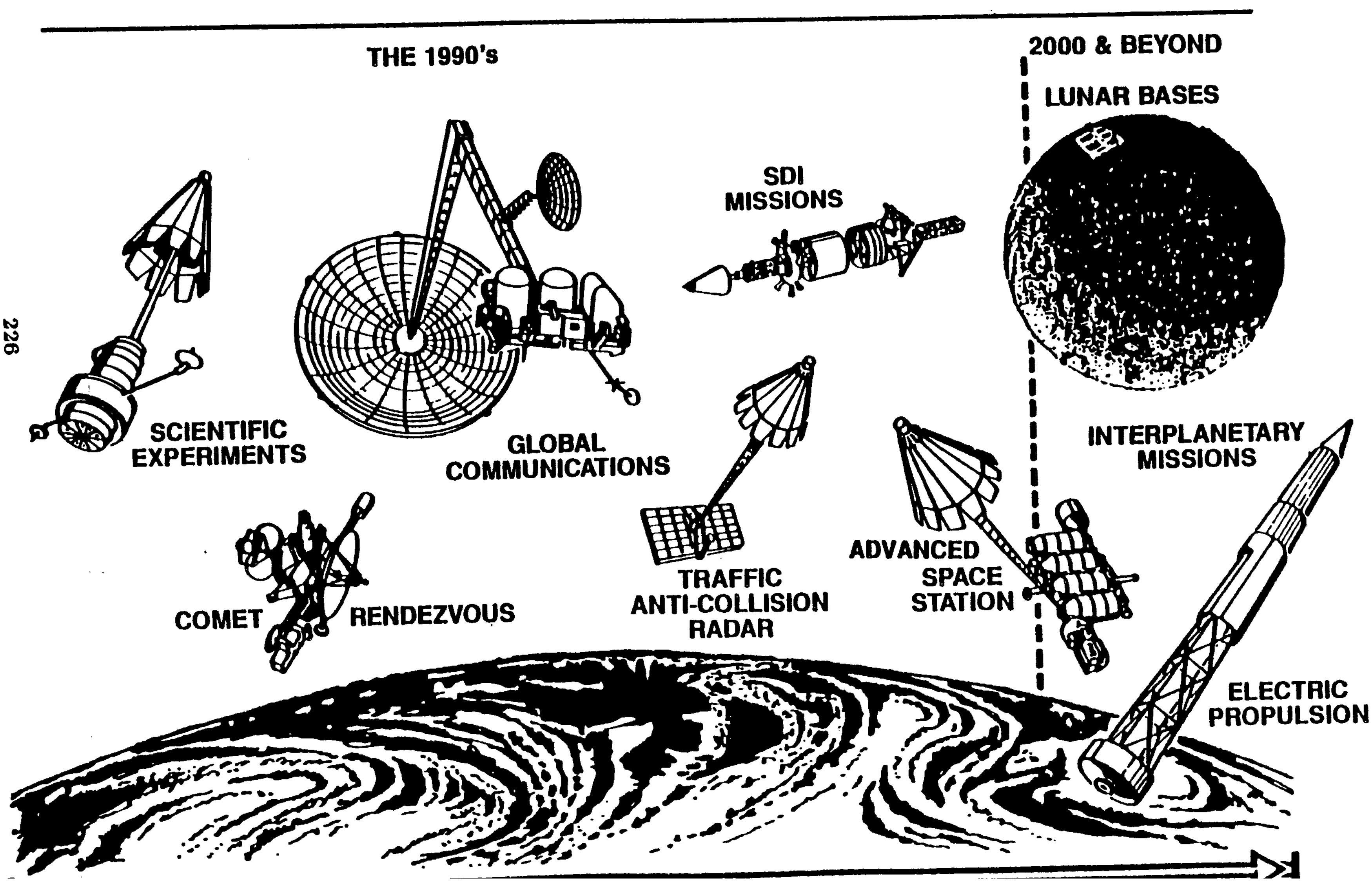
SUMMARY/RECOMMENDATIONS

- SPACE POWER IS A PRECIOUS COMMODITY
- HIGH POWER SIGNIFICANTLY ENHANCES AND ENABLES FUTURE SPACE MISSIONS
- SPACE EXPERIMENTS WILL PROVIDE ASSURANCE OF HIGH TEMPERATURE LIQUID METAL COOLANT, CONVERSION WORKING FLUID & MATERIAL PERFORMANCE AND LIFETIME.
- EXPERIMENTS ARE COMPATIBLE WITH EARLY TO MID '90 STS OPERATIONS

QUALITATIVE RANGE OF APPLICABILITY OF VARIOUS SPACE POWER SYSTEMS



MULTIPLE MISSIONS ANTICIPATED



DYNAMIC AND NUCLEAR SYSTEMS

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ALBUQUERQUE, NEW MEXICO

INTRODUCTION/BACKGROUND

SPACE POWER SYSTEM REQUIREMENTS

-- LONG LIFE (UP TO 10 YEARS)
-- HIGH RELIABILITY (> 0.95)
-- HIGH SPECIFIC POWER (UP TO 100 We/kg)
-- SAFETY (LAUNCH, IN-FLIGHT, IN-ORBIT, AND END OF MISSION DISPOSAL)
-- MODULARITY AND SCALABILITY
-- LOAD - FOLLOWING/AUTONOMOUS OPERATION

ADVANCED TECHNOLOGY NEEDS

-- HIGH TEMPERATURE MATERIALS
-- EFFICIENT AND RELIABLE CONVERTORS (STIRLING, THERMOELECTRICS, THERMIONIC, BRAYTON, RANKINE
-- INSTRUMENTATION/POWER CONDITIONING/HARD ELECTRONICS
-- ROBATICS, SIMULATION, FAULT DETECTION AND AUTONOMY

MISSION APPLICATIONS

-- ORBITING PLATFORMS
-- SPACE STATION
-- LUNAR MISSION SUPPORT APPLICATIONS
-- MARS MISSION SUPPORT APPLICATIONS
-- SPACE AND LUNAR COMMERCIALIZATION ACTIVITIES
-- PLANETARY EXPLORATION SPACECRAFT
-- ORBITAL OPERATIONS SUPPORT VEHICLES

TECHNOLOGY NEEDS

- **<u>THERMAL MANAGEMENT</u>**
  - TWO-PHASE FLOW IN MICROGRAVITY
  - TWO-PHASE SEPARATION IN MICROGRAVITY
  - CONDENSATION AND SEPARATION OF NON-CONDENSIBLE GASES
  - BOILING PHENOMINA/CRITICAL HEAT FLUX/BUBBLE NUCLEATION
  - THAW AND RETHAW IN ORBIT OF LIQUID METAL SYSTEMS
  - CRITICAL FLOW, SURFACE TENSION AND WETTING ANGLE IN-ORBIT
  - INTERFACIAL PHENOMINA (LIQUID/LIQUID AND LIQUID/SOLID)
  - HEAT PIPES TRANSIENT OPERATION AND STARTUP FROM FROZEN STATE
- **<u>MATERIALS</u>**
  - COMPATIBILITY WITH ADVANCED AND REFRACTORY-METAL ALLOYS
  - SELF-DIFFUSION/SELF-WELDING
  - ADVANCED RADIATOR FABRICS/HIGH TEMPERATURE COMPOSITS
  - THERMAL AND ELECTRICAL INSULATION

TECHNOLOGY NEEDS

MATERIALS (CONTINUED)

- EFFECT OF CHARGED PARTICLES (ele & pro) ON OPTICAL PROPERTIES OF SPACECRAFT STRUCTURE MATERIALS
- EFFECTS OF ATOMIC OXYGEN ON POWER CABLES, INSULATION AND STRUCTURE MATERIALS
- LUNAR AND MARTIN SHEILDING MATERIALS

OPERATION AND SAFETY

- AUTOMATION AND AUTONOMY
- AUTOMATION AND CONTROL
- RELIABILITY
- IN-ORBIT THAW AND RETHAW
- CRITICAL FLOW AND INTERFACIAL PHENOMENA
- SURVIVABILITY
- TEMPERATURE, PRESSURE, AND RADIATION SENSORS

IN-SPACE EXPERIMENTS NEEDS/VOIDS

PROOF OF PRINCIPLE EXPERIMENTS (BASIC RESEARCH)

- TWO-PHASE AND TWO-COMPONENT FLOW EXPERIMENTS
- CHANGE-OF-PHASE (MELTING/FREEZING) OF PURE LIQUIDS AND LIQUID-GAS MIXTURES
- INTERACTION OF ATOMIC OXYGEN AND CHARGED PARTICLES WITH THERMAL AND ELECTRIC INSULATION, CABLES, STRUCTURE, RADIATOR SURFACE
- INTERFACIAL PHENOMENA (WETTING, SURFACE AREA, INTERFACE CHARECTERIZATION
- SELF DIFFUSION/ SELF WELDING AND MATERIAL COMPATABILITY
- STARTUP OF HIGH TEMPERATURE HEAT PIPE FROM FROZEN STATE
- ADVANCED HIGH TEMPERATURE ALLOYS INVOLVING HEAVY/ LIGHT ELEMENT
- BOILING AND CONDENSATION OF PURE LIQUIDS/LIQUID MIXTURES
- CRITICAL FLOW EXPERIMENTS

IN-SPACE EXPERIMENTS NEEDS/VOIDS

CONCEPT VERIFICATION EXPERIMENTS OF DEVICES/COMPNENTS

- GAS/VAPOR SEPARATORS
- ADVANCED INSTRUMENTATION/ELECTRONIC DEVICES
- THAW AND RETHAW OF LIQUID METAL LOOPS
- ADVANCE RADIATOR CONCEPTS
- FAULT DETECTION/AUTONOMY SIMULATIONS
- ROTATING DEVICES (NUCLEAR REACTOR CONTROL SYSTEM, STIRLING ENGINE, BRAYTON TURBO-ALTERNATOR, AND RANKINE)
- LOSS-OF-FLOW SIMULATION

SUMMARY/RECOMMENDATIONS

SPACE POWER SYSTEMS DEVELOPMENT AND ADVANCED TECHNOLOGY NEEDS ARE BEST MET BY:

- BASIC RESEARCH AND PROOF OF PRINCIPLE IN-SPACE EXPERIMENTS

- CONCEPT VERIFICATION IN-SPACE EXPERIMENTS OF DEVICE/COMPONENTS

IN-SPACE EXPERIMENTS ARE NECESSARY TO THE SUCCESS OF FUTURE MISSIONS INCLUDING:

- MARS AND LUNAR MISSIONS
- SPACE COMMERCIALIZATION

3.2 CONVENTIONAL POWER SYSTEMS

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CONVENTIONAL POWER SYSTEMS

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INTRODUCTION/BACKGROUND

- **SPACE POWER SYSTEMS OF THE PAST:**
  - Low power-low voltage DC systems
  - High specific mass/high cost per Kw.
- **PRESENT DAY SPACE POWER SYSTEMS:**
  - Improved specific mass
  - Still low power-low voltage DC systems
  - Cost improvements have been accomplished
- **TO ENSURE A VIABLE SPACE PROGRAM, POWER SYSTEMS OF THE FUTURE MUST HAVE GREATLY IMPROVED ATTRIBUTES:**
  - High power-high voltage AC systems
  - Significant reductions in weight
  - Significant reductions in costs

MISSION APPLICATIONS

- Planetary exploration spacecraft
- Earth surveilance satellites
- Earth resource satellites
- Communication satellites
- Space station
- Orbiting platforms
- Lunar mission support applications
- Mars mission support applications
- Orbital operations support vehicles
- Cis-lunar transportation vehicles
- Space commercialization activities

TECHNOLOGY NEEDS/CRITICAL TECHNOLOGIES

- **SOLAR PHOTOVOLTAIC CELLS**
  - High efficiency/lightweight solar cells
  - Radiation tolerant cells
  - Lightweight solar arrays
    Deployable
    Stowable
  - Refractive concentrator development
- **HIGH ENERGY DENSITY STORAGE SYSTEMS**
  - Advanced batteries
  - Regenerative fuel cells
  - Inertial energy storage
  - Superconducting magnetic energy storage
- **POWER MANAGEMENT AND DISTRIBUTION SYSTEMS**
  - High power/high voltage systems
  - High frequency AC components and devices
  - Fault tolerant power systems and components
  - Autonomous power systems operation

TECHNOLOGY NEEDS/CRITICAL TECHNOLOGIES

- **MATERIALS**
  - Materials for high power-high voltage sytems
    - Insulators
    - Conductors
    - Thermal control materials
  - Materials compatibility with operating environment

- **ENVIRONMENTAL INTERACTIONS**
  - Design criteria for power system space operating environment comparibility
    - High voltage operation
    - Spacecraft charging/discharging phenomena
  - Design criteria for power system planetary environment conpatibility
    - Lunar surface operation
    - Martian atmosphere environment

IN-SPACE EXPERIMENTS NEEDS/VOIDS

Power Technology Development Experiments Can Be Put Into The Following Three Broad Categories:

I. Proof of principle experiments (Basic research)

II. Concept verification experiments of devices/components

III. Design/operational readiness verification tests of systems in space

The Space Power In-Space Experiments program is directed towrd category I and II experiments:

- In support of the OAST Base Research and Technology Program
- To support the Civil Space Technology Initiative
- To support the Pathfinder Program

IN-SPACE EXPERIMENTS NEEDS/VOIDS

ELEMENTS	SPACE ENERGY CONVERSION R&T (FY 89, 90, 91, 92, 93)	REQUIREMENTS/GOALS	IN SPACE EXPERIMENTS SUPPORT
PHOTOVOLTAIC ENERGY CONVERSION	ADVANCED PV CELL TECH. HIGH PERFORM. ARRAYS HIGH POWER ARRAYS	● PROVIDE TECH BASE FOR HIGH POWER TO WEIGHT, LONG LIFE PV ARRAYS FOR LEO, GEO, AND SOLAR EXPLORATION MISSIONS.	▼ 1990: Short term (hours-days) exposure at LEO for calibration ofspace solar cells. ▼ 1994: Long term (years) exposure in low earth, polar, and mid-altitude orbits to determine performance of new cells, blankets and concentrator elements in the actual space environment.
CHEMICAL ENERGY CONVERSION	PRIMARY-SECOND. BATT'S. ADVAN. EC ENER. STORAGE PRIM. & REGEN. FUEL CELL	● ENHANCE UNDER-STANDING OF EC TECNOLOGIES ● HIGH ENERGY DENS. LONG LIFE PRIMARY AND SECONDARY BATTERIES AND PRIM. AND REGEN. FUEL CELLS. ● DEVELOP AND EVAL. ADVANCED CONCEPTS FOR SPACE EC SYSTEMS.	▼ 1990: Experiments to compile a technology data base on electro-chemical phenomena; - Bubble/droplet formation on electrodes. - Convecting forces-kinetics, two phase flow, liquid and gas management, current effects in electro-chemucal systems in micro-gravity. ▼ 1992: Verify the performance of advanced EC systems such NaS, batteries, H2O2 regen. fuel cells, H2BR fuel cells in micro-gravity.
POWER MANAGEMENT	HI VOLT.-HI POW. SYST'S. HI DENSITY POWER SYST'S. LASER POWER TRANSMISSION POWER INTEG. CIRCUITS	● PROVIDE TECH. BASE IN ANALYTICAL AND COMPONENT TECHNOL. NECESSARY FOR FOR MANAGEMENT AND DISTRIBUTION OF POWER ON FUTURE NASA SPACE MISSIONS	▼ 1990: Demonstrate in-space performance of passive high thermal conductivity power system heat rejection techniques utilizing graphite fiber composite materials.
POWER SYSTEM MATERIALS	SOL. ARRAY BLANKET MAT'S SOL. DYNAM. CONCENT'S.	● PROVIDE TECHNOLOGY FOR LONG LIFE-HIGH PERFORMANCE POWER SYSTEM MATERIALS.	▼ 1990: Provide in-space verification of ground simulation systems for LEO atomic oxygen durability testing.
SPACE ENVIRONM'T. INTERACT'S.	NASACP LEO DEVEL&VALIDAT ARC MEAS'M'TS/AC EFFECTS CSTI; NUCLEAR ELECTRIC PATHFINDER: DUST-LOW PRESSURE INTERACTIONS	o PROVIDE MODELING AND ANALYSIS CAPABILITY TO ENABLE DESIGN OF ENVIRONMENTALLY COMPATIBLE SPACE SYSTEMS.	▼ 1990: Plasma interaction experiments with solar arrays. ▼ 1992: Ion thruster efflux characterization. ▼ 1993; In-space verification of high voltage AC power system interactions. ▼ 2000: Mars surface high-voltage effects.

NOTES: ▲ R&T PROGRAM MILESTONES. (Experiment dates shown are definition phase start dates). (KAF: 10/15/88; 210.)

IN-SPACE EXPERIMENTS NEEDS/VOIDS

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000

- SHORT TERM EXPOSURE TESTS OF PV CELLS
- EXPERIMENTS TO COMPILE DATA ON ELECTROCHEMICAL PHENOMENA
- SHORT TERM MATERIALS TESTING
- ION THRUSTER EFFLUX CHARACTERIZATION

- LONG TERM EXPOSURE TESTS OF NEW SOLAR CELLS, BLANKETS, ARRAYS, ETC.
- LONG TERM EXPOSURE TESTING OF POWER SYSTEM MATERIALS

- DEVELOPMENT EXPERIMENTS ON ADVANCED BATTERIES
- PLASMA INTERACTION EXPERIMENTS FOR SOLAR ARRAYS
- IN-SPACE PERFORMANCE OF HEAT REJECTION TECHNIQUES

- IN-SPACE VERIFICATION OF HIGH-VOLTAGE POWER SYSTEMS INTERACTIONS-OPERATIONS

PHOTOVOLTAICS
HIGH ENERGY DENSITY STORAGE
POWER MANAGEMENT AND DISTRIBUTION
ENVIRONMENTAL INTERACTIONS
MATERIALS FOR POWER SYSTEMS

Conventional Power Systems

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High Priority Technology Objectives

- **Better Batteries**
  - Lower weight (higher w-hr/lb)
  - Higher capacity (up to about 200 A-hr)
  - Longer activated shelf life (cost and schedule issue)
  - Less expensive
  - Improved volume efficiency
  - Improved thermal design/thermal interface (esp. for IPV NiH_2)
  - Lower temperature sensitivity
    - Higher operating temperature range

  - Most promising near-term technologies
    - CPV NiH_2 - Low cost and high performance
    - NaS - high performance

High Priority Technology Objectives

- **Better Solar Cells/Arrays**
  - Higher efficiency
  - Lower weight (thin cells, spray-on cover glass)
  - Improved radiation hardness
    - Eliminate need for cover glass
  - UV tolerant adhesive and cells
  - Lower cost
  - Built-in reverse voltage protection
  - Improved interconnections
  - Concentrator technologies (especially for laser hardening)

High Priority Technology Objectives

- **High voltage power distribution switch gear**
  - 50, 100, 200 VDC operation
  - 1, 2, 5, 10, 20, 50, 100 ADC operation

- Switches with "relay-like" characteristics
  - High efficiency (> 99.9%)
  - Permanent memory
  - High noise immunity, command/power ground isolation
  - Light weight
  - High reliability
  - Low cost
  - High surge-carrying capability
- Fuses
  - High reliability, hermetically sealed
  - Sturdy, lightweight

High Priority Technology Objectives

- **Capacitors**
  - 100, 200, 400 VDC operation
  - 1, 10, 20, 50, 100 microfarads
  - Low ESR, high AC current rating
  - Volumetrically efficient
  - High resonant frequency
  - Light weight
  - Fail-safe (ie. no permanent short circuit failure mode)
- **Radiation Hardened Power MOSFETs**
  - Higher power ratings
  - Prompt response hard (X-ray)
  - Single event upset hard (cosmic ray)
- **Combined Technology Power Control Building Blocks**
  - Analog, digital, and power devices in standard building block packages (power hybrids)
    - Digital input signal, high power switch output.
  - Could be part of enabling technology for resonant and quasi-resonant converters with promise of > 2:1 power density improvement

In-Space Experiments Needs (Near-Term)

- Qualification of most power systems equipment can be satisfactorily accomplished without in-space demonstration.
  - Exception - Equipment possibly sensitive to micro-gravity such as batteries.
- Biggest need for flight experiments is to better define the characteristics of certain space environments. Better environment models will permit improved performance analyses/predictions and thus better designs.
  - Space plasma
    - Effect on high-voltage solar arrays
    - ESD
  - Atomic oxygen
  - Charged partical environment in mid-altitude orbits
    - Possible effect on UV degradation

Suggested In-Space Experiment

Contamination, U-V and Charged Particle Induced Solar Array Effects

Concerns Unresolved degradation of solar arrays due to space UV/charged particle radiation effects; Unresolved UV/charge particle degradation on advanced cell types.

Objectives Establish design criteria for UV/charge particle radiation effects on contamination; Establish design criteria for UV/charged particle radiation effects on advanced cell types.

Variables Orbit charged particle environment, contamination type and amount, solar cell type/configuration, solar array components other than solar cells (covers, adhesives, etc.)

Approach Test articles flown would be designed to test for UV, radiation and contaminant degradation. Various thickness of coverglass would be used to factor radiation, etc. Entire I-V curves would be measured periodically.

Suggested In-Space Experiment

Plasma Induced Solar Array Effects

Concerns Degradation of solar cells/solar arrays due to the plasma environment.

Objectives Establish design criteria for advanced array designs operating in plasma environments.

Variables Orbit/plasma environment, solar array operating voltage, solar cell type/configuration, solar array components other than solar cells (covers, adhesives, insulators, etc.), solar array layout.

Approach Test articles to be flown would be designed to include as many advanced concepts as practical.

CONVENTIONAL POWER SYSTEMS

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OVERVIEW

- SPACE POWER SYSTEMS
  - -MULTIDISCIPLINARY TECHNOLOGY REQUIRED
  - -SYSTEM ADVANCES ARE INCREMENTAL
  - -UNIQUE POWER-ENVIRONMENT COUPLING
- CURRENT STATE-OF-ART
  - -A FEW KILOWATTS
  - -LOW VOLTAGE-HIGH CURRENT
- FUTURE NEEDS
  - -HUNDREDS OF KILOWATTS-MEGAWATTS
  - -EXTREME RELIABILITY/AUTONOMY
  - -MINIMUM REDUNDANCY/MAXIMUM SELF HEALING
  - -HIGHER VOLTAGE OPERATIONS
  - -BROAD PARAMETER RANGE DATABASE
- UNIQUE UNIVERSITY ROLE
  - -ALL DISCIPLINES REPRESENTED AT MAJOR UNIVERSITY
  - -DIFFERENCE BETWEEN SOA AND PROJECTED NEEDS MAKE "FIRST PRINCIPLES" APPROACHES ATTRACTIVE
  - -PARALLEL EFFORTS ARE COST EFFECTIVE
  - -EDUCATION OF SPACE POWER ENGINEERS AND SCIENTISTS

MISSION APPLICATIONS

- PLANETARY EXPLORATION SPACECRAFT
- EARTH SURVEILANCE SATELLITES
- EARTH RESOURCE SATELLITES
- COMMUNICATION SATELLTIES
- SPACE STATION
- ORBITING PLATFORMS
- LUNAR MISSION SUPPORT APPLICATIONS
- MARS MISSION SUPPORT APPLICATIONS
- ORBITAL OPERATIONS SUPPORT VEHICLES
- CIS-LUNAR TRANSPORTATION VEHICLES
- SPACE COMMERCIALIZATION ACTIVITIES

NEEDED RESEARCH FOCUS TOPICS

- SOLAR PHOTOVOLTAIC CELLS
  - -METAL/SEMI-CONDUCTOR/INSULATOR INTERFACE PHENOMENA
  - -QUANTIUM WELLS/GRADED BAND GAP DEVICES/SUPER LATTICE
  - -DEGREDATION MECHANISMS
  - -MULTISTIMULUS SPACE EFFECTS
- HIGH ENERGY DENSITY STORAGE SYSTEMS
  - -FAILURE MECHANISMS
  - -ELECTRODE PHENOMENA
  - -OPERATION IN RADIATION ENVIRONMENT
  - -VACUUM OPERATION
  - -SAFETY ISSUES
  - -OPERATION IN O "g"
- POWER MANAGEMENT AND DISTRIBUTION SYSTEMS
  - -INTEGRATION OF AI/EXPERT SYSTEM INTO POWER/THERMAL MANAGEMENT
  - -EFFECTS OF ENVIRONMENT INDUCED SYSTEM ERRORS
  - -VOTING LOGIC IN AI
  - -SELF HEALING COMPONENTS
  - -FAULT MANAGEMENT TECHNIQUES
  - -ADVANCED DIAGNOSTIC SUITES/NEW SENSORS
  - -DISTRIBUTION SYSTEM/ENVIRONMENTAL INTERACTIONS--EFFECTS & LIMITS
  - -POWER (V-I CHARACTERISTICS)/THERMAL MANAGEMENT TRADE OFF IMPLICATIONS

NEEDED RESEARCH FOCUS TOPICS (CONTINUED)

- <u>MATERIALS</u>
  - -NEW CLASSES OPTIMIZED FOR LONG TERM SPACE EXPOSURE
  - -DETAILED UNDERSTANDING OF MATERIALS RESPONSE
  - -SELF HEALING MATERIALS/COATINGS
  - -CONTAMINATION MECHANISMS
- <u>ENVIRONMENTAL INTERACTIONS</u>
  - -POWER/PLATFORM/ENVIRONMENT SYNERGISM
  - -LONG TERM EVOLUTION OF LOCAL ENVIRONMENT
  - -LIMITS IMPOSED ON POWER SYSTEM PARAMETER SPACE
- <u>SIMULATION</u>
  - -THEORY & MODELING
  - -ADVANCED MULTISTIMULUS FACILITIES
  - -ACCELERATED AGING METHODOLOGY
  - -BENCHMARK SPACE EXPERIMENTS

IN-SPACE EXPERIMENTAL NEEDS

EXPERIMENT	ISSUES	FOCUS
Dynamics of high current arcs in 0 "g"	Gas switch operation. Fault management.	Effects of 0 "g" on switch stability/ reliability. Control of arc faults in contaminated space environments.
0 "g" liquid/solid phase change dynamics.	Thermal energy storage.	Two phase component separation. Effects on thermal conductivity.
Spatial and temporal evolution of space debris.	Surface flashover. Corona discharges.	Insulation degradation debris migration in electrical/magnetic fields.

IN-SPACE EXPERIMENTS NEEDS/VOIDS

- ACCURATE CHARACTERIZATION OF SPACE ENVIRONMENT & ITS EVOLUTION
- VERIFY SIMULATION & MODELING OF SPACE ENVIRONMENT
- ACCURATE DETERMINATION OF PLATFORM ROLE IN LONG TERM EVOLUTION OF LOCAL SPACE ENVIRONMENT
- BENCHMARK EXPOSURE (LDEF) TO DETERMINE ADEQUACY OF SIMULATION OF LONG TERM EXPOSURE
- ELECTRICAL CHARACTERIZATION OF SPACE ENVIRONMENT
- LONG TERM CONTROLLABLE MICROGRAVITY LABORATORY

CRITICAL TECHNOLOGIES

1. HIGH EFFICIENCY SOLAR CELL TECHNOLOGY
2. HIGH ENERGY DENSITY ENERGY STORAGE SYSTEMS
3. NEW MATERIALS TECHNOLOGY SPECIFICALLY OPTIMIZED FOR LONG TERM SPACE APPLICATIONS
4. ADVANCED DIAGNOSTIC TECHNIQUES EMPLOYING AI/EXPERT SYSTEMS
5. FAULT TOLERANT POWER SYSTEMS
6. MULTISTIMULUS SPACE SIMULATION FACILITIES
7. HIGH EFFICIENCY THERMAL MANAGEMENT TECHNOLOGY
8. HIGH EFFICIENCY HIGH TEMPERATURE ELECTRONICS

3.3 THERMAL MANAGEMENT

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. . . . . GOVERNMENT VIEW . . . . . .

SPACECRAFT THERMAL MANAGEMENT REQUIREMENTS AND TECHNOLOGY NEEDS

PRESENTATION TO
NASA IN-STEP WORKSHOP
ATLANTA, GEORGIA
6-9 DECEMBER 1988

DR. TOM MAHEFKEY
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PRELIMINARY REMARKS

- THERE ARE SIGNIFICANT DIFFERENCES AMONG SPONSORING AGENCIES RELATED TO MISSIONS, GOALS, OBJECTIVES, POLICIES, AND ATTITUDES...
- THERE IS THUS NO SINGLE OVERALL GOVERNMENT VIEWPOINT RELATED TO TECHNOLOGY NEEDS, R&D PRIORITIES, INVESTMENT STRATEGIES, AND PROGRAMMATIC POLICIES
- THIS PRESENTATION ADRESSES ONLY THE MISSION IMPLIED TECHNOLOGY NEEDS AND LIKELY "NATIONAL" DIRECTION IN SPACECRAFT THERMAL MANAGEMENT R&D

THE NATIONS SPACE MISSION SET

NASA MISSIONS

- Δ INTERPLANETARY/DEEP SPACE SCIENCE PLATFORMS, MANNED MISSIONS
- Δ EARTH RESOURCES/NEAR EARTH SCIENCE PLATFORMS
- Δ COMMUNICATIONS
- Δ SPACE STATION....SCIENCE PLATFORM, SPACE MAN'F, LAUNCH PLATFORM
- Δ LUNAR BASE
- Δ NASP

DOD MISSIONS

- Δ NAVIGATION, METEOROLOGY....
- Δ SURVEILLANCE, EARLY WARNING....
- Δ COMMUNICATIONS
- Δ DEFENSE FROM SPACE (SDI)....
- Δ NASP, HLLV, ALS

KEY DIFFERENCES

- MILITARY MISSIONS ALL NEAR EARTH
- MILITARY MISSIONS MUST BE SURVIVABLE
- OPERATING ORBITS, MASS TO ORBIT
- MANNED VS. UNMANNED
- SPACE MAINTAINABLE VS. AUTONOMOUS

NASA/DOD THERMAL MANAGEMENT NEEDS CONTRASTED

	NASA	DOD
□ HEAT AQUISITION		
• 10-100K	√ IR SENSORS √ PROPELLANT DEPOT, DELIVERY	√ SIMILAR SENSORS √ CRYO-COOLED DEW LOADS √ HIGHER POWER, LOWER ALLOWABLE ΔT
• 300-400K	√ MANNED HABITAT ECS √ PAYLOAD ELECTRONICS COOLING √ THERMAL BUS DISTRIBUTED LOADS	√ PRIMARILY UNMANNED √ LONG LIFE ELECTRONICS-DENSER PACKAGING, HIGHER FLUXES √ DISCRETE AND DISTRIBUTED LOADS
• 600-2000K	√ ENERGY CONVERSION DEVICE COOLING SOLAR DYNAMIC, SP-100 REACTOR √ SPACE MANUFACTURING PROCESS HEAT	√ BOTH BASELOAD AND BURST POWER COOLING
□ HEAT TRANSPORT	√ LEO MAINTAINABLE ALLOWED √ COST VS. MASS-TO-ORBIT DRIVEN √ PRIMARILY CLOSED CYCLE, STEADY STATE √ TO 100 kW/100M REGIME √ MICRO-G ENVIRONMENT	√ AUTONOMY, LONG UNATTENDED LIFE √ MASS-TO-ORBIT VS. COST DRIVEN √ BOTH OPEN/CLOSED CYCLE, HIGH PEAK TO AVERAGE PROFILES √ TO 100MW-100M REGIME √ MACRO-G ENVIRONMENT
□ HEAT REJECTION	√ SPACE ERECTIBLE RADIATORS √ LEO, INTERPLANETARY, LUNAR NATURAL ENVIRONMENT SURVIVABILITY	√ DEPLOYABLE √ LEO-GEO ORBIT, NATURAL AND MILITARY THREAT ENVIRONMENT

COMMON NASA/DOD R&D NEEDS- TWO-PHASE HEAT TRANSPORT

- HIGH TRANSPORT CAPACITY HEAT PIPES....CRYOGENIC THROUGH LIQUID METAL TEMPERATURE REGIMES...SCALING VALIDITY FOR CAPILLARY LOOPS, SUBCOOLING SIMILARITY DEMONSTRATION

- STEADY STATE HEAT TRANSFER - EXPERIMENTAL DATA ON CO-CURRENT, COUNTER CURRENT HEAT AND MASS TRANSFER...AUGMENTATION EFFECTIVENESS

- UNSTEADY HEAT TRANSFER - FROZEN AND SUPERCRITICAL START-UP...MICRO TO MACRO "G" INFLUENCES ON PRIMING, DEPRIMING...VOID FORMATION IN T.E.S. FREEZING/MELTING...

- MASS TRANSFER - HEAT PUMP LUBRICANT/REFRIGERANT SEPARATION, LIQUID REACTANT DELIVERY, VAPOR VENTING SEPARATION

- MICRO/MACRO "G" FLOW STABILITY REGIMES - GAS COOLED REACTOR START-UP, EXPANDABLE VOLUME RADIATORS...TRANSIENT AND PERIODIC CRYO-COOLED LOAD COOLING...VIBRATIONALLY INDUCED INSTABILITY

SUMMARY

- THERE ARE SIGNIFICANT DIFFERENCES IN THE APPLICATIONS AND OPERATING REGIMES OF THERMAL MANAGEMENT TECHNOLOGIES FOR MILITARY AND CIVILIAN MISSIONS....

- THE BASIC TECHNOLOGIES/TECHNICAL DISCIPLINES ARE THE SAME...THE SPECIFIC MISSION NEEDS NECESSITATE CHARACTERIZING THE TECHNOLOGY OVER WIDER REGIMES OF PERFORMANCE...

- MILITARY MISSIONS ARE MORE STRONGLY DRIVEN BY PERFORMANCE, LIFE, AND RELIABILITY......

- THE NEED FOR MICRO/MACRO "G" IN-SPACE PERFORMANCE VERIFACATION EXISTS FOR BOTH MILITARY AND CIVILIAN MISSIONS...SPECTRUM OF NEEDS RANGE FROM FUNDAMENTAL PHENOMENA CHARACTERIZATION \TO FLIGHT - READINESS VERIFACATION.....

Thermal Management

An Industry Viewpoint

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Introduction/Background

- Focus on zero "g" issues
  - Not simulated on earth
  - Large time constant effects

- Identified
  - Technology needs and voids
  - Experiments
  - Facilities

- Recommendations

Technology Needs

- Basic zero "g" phenomena
  - Evaporation/boiling
  - Condensation
  - Two-phase flow
    - — Pressure drop
    - — Flow regimes
    - — Stability
  - Surface tension effects
  - Wet wall dryout
  - Diffusion controlled processes
  - Droplet dynamics
- Supports component optimization and acceptable design conservatism

Technology Needs

- Component performance in zero "g"
  - Flow stability
  - Pressure drop
  - Heat transfer effectiveness
  - Isothermality
  - Priming
  - Freezing and recovery
  - Induced accelerations (maneuvering)

- Component candidates
  - Heat pipes
  - Evaporators
  - Condensers
  - Two-phase system components
    - — Tee's
    - — Valves
    - — Pumps
  - Thermal storage
  - Accumulators/reservoirs
  - Instrumentation

- Supports subsystem and system optimization

In-Space Experimentation Needs/Voids

- Two-phase heat transfer
- Two-phase flow
- Heat pipes
  - Liquid metal
  - Unusual geometry/size
  - Cryogenic
- Two-phase fluid storage/reservoir
- Thermal storage
- Capillary loops
- Two-phase loops
- Zero "g" and short term accelerations

In-Space Experimentation Needs/Voids

- New facilities
  - Multi-use
  - Well-defined interfaces
  - Industry and academia inputs
- Two-phase fluid (NH_3) test bed
- Cryogenic test bed
- High-temperature test bed
- Long term operation and exposure test bed

THERMAL MANAGEMENT ISSUES

IN

ADVANCED SPACE MISSIONS

UNIVERSITY VIEWPOINT

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INTRODUCTION

- Thermal Management Required for:
  - Inhabitants (Environment)
  - Spacecraft Systems
  - On Board Experiments
- Thermal Management Includes:
  - Heat Acquisition and Transport
  - Heat Rejection
  - System Integration
- Single Phase Loops and Systems Suitable for Small Vehicles
- Two Phase Thermal Loops Are Capable of:
  - Higher Transport Capabilities
  - Constant Temperature Performance

INTRODUCTION, CONTINUED

- Problems Inherent in Two Phase Systems
  - Working Fluids
  - Vapor and Condensate Removal
  - Liquid-Vapor Interfacial Behavior
  - Phase Distribution
- Problems Inherent in Heat Rejection Systems
  - Radiating Area per Unit Weight
  - Contact Resistance
  - Thermal Storage

IN-SPACE EXPERIMENTATION: NEEDS/VOIDS

- Heat Acquisition and Transport, General
  - Fundamental Physical Measurements Leading to Q and ΔP Correlations (data limited to drop tower and aircraft trajectories)
    - Flow Rates
    - Temperatures
    - Pressure (Drops)
    - Heat Transfer Rates
    - Quality (Void Fraction)
    - Configuration
  - Photographic Observations (data limited to aircraft trajectories)
    - Flow Patterns/Phase Distribution
    - Interfacial Dynamics
    - Secondary Flows

IN-SPACE EXPERIMENTATION: NEEDS/VOIDS, CONTINUED

- Heat Acquisition and Transport, Specific Components

  (Complete Data Void for Almost All of These Components)

  - Tube Farms
  - Condensers
    - Capillary-Pumped
    - Shear Flow
  - Evaporators
    - Swirl Flow
    - Monogroove
  - Pumping Systems
    - Rotary Fluid Management Devices (Pilot Pump)
  - Load/Flow Control Strategies

SUMMARY/RECOMMENDATIONS

<u>NEAR-TERM RECOMMENDATION</u>

- Develop a Comprehensive In-Space Test Program for Behavior of Multi-Phase Fluids
- Perform as much Preliminary Work as Possible in Earth Labs, Centrifuges, Drop Towers, and Aircraft

<u>LONG-TERM RECOMMENDATIONS</u>

- Testing of Advanced Radiators
- In-Space Testing of Heat Pumps
- Testing of Thermal Storage Systems

POWER SYSTEMS AND THERMAL MANAGEMENT CRITICAL TECHNOLOGY REQUIREMENTS

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GODDARD SPACE FLIGHT CENTER

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP
DECEMBER 6-9, 1988

PARTICIPANTS: 66

SUBTHEMES

- DYNAMIC AND NUCLEAR POWER SYSTEMS
- CONVENTIONAL POWER SYSTEMS
- THERMAL MANAGEMENT

DYNAMIC AND NUCLEAR POWER SYSTEMS

	VOTES *
1. GAS COLLECTION AND RETENTION IN LIQ COOLANTS	372
2. FREEZE/THAW IN LIQ METAL SYSTEMS	317
3. GAS BUBBLE NUCLEATION/GROWTH IN LIQ METALS	238
4. TWO COMPONENT (SOLID/LIQUID) PUMPING/SEPARATION	221
5. TWO PHASE LIQ/GAS SEPARATION IN COOLANTS	197
6. LIGHT WEIGHT RADIATORS	173
7. TWO PHASE BOILING	171
8. PLASMA INTERACTION	158
9. ADVANCED POWER CONVERSION SYSTEMS	147
10. ENVIRONMENTAL EFFECTS	133

* Technology issues were ranked from 1 to 10, with the most important receiving 10 votes, the next 9 votes, etc.

CONVENTIONAL POWER SYSTEMS

	VOTES*
1. ADVANCED ENERGY STORAGE	243
2. ADVANCED P.V. CELL TECHNOLOGY	200
3. PRIMARY & REGEN. FUEL CELLS	197
4. THERMAL ENERGY STORAGE	162
5. CONTAMINATION/UV & CHARGED PARTICLE P.V. EFFECTS	155
6. PRIMARY/SECONDARY BATTERIES	154
7. HIGH VOLTAGE/HIGH POWER SYSTEMS	146
8. HIGH PERFORMANCE ARRYS	142
9. HIGH DENSITY POWER SYSTEMS	141
10. HIGH POWER ARRAYS	138

* Technology issues were ranked from 1 to 10, with the most important receiving 10 votes, the next 9 votes, etc.

THERMAL MANAGEMENT

	VOTES *
1. TWO-PHASE HEAT TRANSFER	328
2. HEAT PIPES (LIQUID METAL CYRO)	250
3. CAPILLARY LOOPS	225
4. TWO PHASE FLOW & STABILITY	219
5. VOID BEHAVIOR FLIGHT TEST	201
6. HEAT PUMPS	185
7. TWO-PHASE AMMONIA TEST BED	182
8. THERMAL STORAGE	152
9. CYROGENIC TEST BED	139
10. ADVANCED RADIATORS	136

* Technology issues were ranked from 1 to 10, with the most important receiving 10 votes, the next 9 votes, etc.

CRITICAL TECHNOLOGIES

DYNAMIC AND NUCLEAR POWER SYSTEMS

1. TWO COMPONENT FLOW AND PHASE CHANGE
    - He GAS NUCLEATION, SEPARATION AND COLLECTION
    - FREEZE/THAW (SYSTEMS)
    - KINETICS OF VOID FORMATION AND DISTRIBUTION BEHAVIOR

2. ADVANCED CONVERSION
    - HIGH EFFICIENCY PASSIVE CONVERSION (AMTEC, HYTEC)
    - DYNAMIC CONVERSION VALIDATION (STIRLING, BRAYTON)

CRITICAL TECHNOLOGIES

CONVENTIONAL POWER SYSTEMS

1. MICRO-GRAVITY EFFECTS ON ADVANCED ELECTROCHEMICAL CONVERSION/STORAGE
    - REGENERATIVE FUEL CELLS
    - CELLS/BATTERIES

2. ADVANCED PHOTOVOLTAIC TECHNOLOGY
    - ENVIRONMENTAL EFFECTS (CELLS/CELL ASSEMBLIES)
        - SPACECRAFT INDUCED ENVIRONMENT
        - NATURAL ENVIRONMENT

CRITICAL TECHNOLOGIES

THERMAL MANAGEMENT

1. TWO-PHASE FLOW STUDIES (TEST BED)
   - FUNDAMENTAL THERMAL HYDRAULICS
     - HEAT TRANSFER
     - INSTABILITIES
     - PRESSURE DROPS
   - SYSTEM AND COMPONENT RELATED STUDIES
     - CAPILLARY PUMPED LOOPS
     - HEAT PUMP ISSUES
     - FLOW MANAGEMENT
2. ADVANCED HEAT PIPES
   - CRYOGENIC HEAT PIPES
   - LIQUID METAL HEAT PIPES
   - INTERMEDIATE TEMPERATURE HEAT PIPES

INTERACTIONS WITH OTHER THEMES

THEME	CONCERN
SPACE STRUCTURES	• SOLAR ARRAY DEPLOYMENT VIBRATION CONTROL
SPACE ENVIRONMENTAL EFFECTS	• ATOMIC OXYGEN DEGRADATION OF HIGH TEMP/HIGH E SURFACES • ENVIRONMENTAL EFFECTS ON POWER SYSTEM COMPONENTS • EFFECTS DATA BASE
AUTOMATION AND ROBOTICS	• ON-ORBIT MAINTENANCE/REPAIR • ARTIFICIAL INTELLIGENCE FOR POWER THERMAL SYSTEM CONTROL
IN SPACE SYSTEMS	• JOINING/WELDING

4. FLUID MANAGEMENT AND PROPULSION SYSTEMS

FLUID MANAGEMENT & PROPULSION SYSTEMS BACKGROUND AND OBJECTIVES

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ORGANIZATION

THEME LEADER: LYNN M. ANDERSON, LeRC

COMMITTEE:
EARL E. VANLANDINGHAM, OAST/RP
WALTER F. BROOKS, ARC
WILBERT ELLIS, JSC
E. JOHN ROSCHKE, JPL
KARL A. FAYMON, LeRC
JOHN M. KRAMER, MSFC
PLUS SUB-THEME SPEAKERS

SUB-THEMES:
1. ON-ORBT FLUID MANAGEMENT
2. PROPULSION
3. FLUID PHYSICS

THEME SESSION OBJECTIVES

PURPOSE

- Identify and prioritize in-space technologies for fluid management and propulsions systems by considering subtheme details which
  - are critical for future U.S. space programs.
  - require development and in-space validation.
- Generate comments and suggestions from aerospace community on OAST IN-STEP plans.

PRODUCT

- Priority listing of critical space technology needs and associated space flight experiments, recommended by aerospace community.

4.1 ON-ORBIT FLUID MANAGEMENT

FLUID MANAGEMENT TECHNOLOGY

JOHN C. AYDELOTT

NASA - LEWIS RESEARCH CENTER

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY ROADMAP

- EXAMINE FUTURE MISSIONS TO ESTABLISH NEEDS
  - EARTH-TO-ORBIT TRANSPORT OF CRYOGENS
  - IN-SPACE STORAGE AND SUPPLY (DEPOT)
  - FUELING OF SPACE-BASED TRANSFER VEHICLES
  - EXPERIMENT AND SATELLITE COOLANT RESUPPLY
  - HANDLING OF REACTANTS, COOLANTS, AND PROPELLANTS ON SPACE DEFENSE INITIATIVE SPACECRAFT

- CATEGORIZE TECHNOLOGY AND IDENTIFY IN-SPACE EXPERIMENTATION REQUIREMENTS
  - LIQUID STORAGE (THERMAL AND PRESSURE CONTROL)
  - LIQUID SUPPLY (PRESSURIZE, ACQUIRE, AND SUBCOOL)
  - LIQUID TRANSFER
  - FLUID HANDLING
  - INSTRUMENTATION
  - STRUCTURES AND MATERIALS

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY REQUIREMENTS

LIQUID STORAGE - THERMAL CONTROL SYSTEM PERFORMANCE

- EFFECT OF LAUNCH ENVIRONMENT ON THICK MULTILAYER INSULATION
- *LONG TERM SPACE ENVIRONMENT EFFECTS ON INSULATION (DEBRIS, MICROMETEROIDS AND ATOMIC OXYGEN)*
- COMBINED EARTH/ORBIT INSULATION
- COOLING ENHANCEMENT PROVIDED BY PARA-TO-ORTHO CONVERSION
- MULTIPLE/COUPLED VAPOR COOLED SHIELDS

LIQUID STORAGE - PRESSURE CONTROL

- *THERMODYNAMIC VENT SYSTEM PERFORMANCE*
- *FLUID MIXING FOR STRATIFICATION CONTROL*
- REFRIGERATION/LIQUEFACTION SYSTEM DEMONSTRATION (INCLUDING CONDENSATE COLLECTION)

Italicized items must be addressed via flight experiments, however, some information can be obtained via ground based experiments

SPACE FLIGHT SYSTEMS DIRECTORATE

CRYOGENIC FLUIDS TECHNOLOGY OFFICE

NASA Lewis Research Center

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY REQUIREMENTS

LIQUID SUPPLY - PRESSURIZATION SYSTEM PERFORMANCE

- *AUTOGENOUS (INCLUDING PARA/ORTHO COMPOSITION)*
- *HELIUM*
- MECHANICAL (PUMPS/COMPRESSORS)

LIQUID SUPPLY - FLUID ACQUISITION/SUBCOOLING

- *FINE MESH SCREEN LIQUID ACQUISITION DEVICE (LAD) EXPULSION EFFICIENCY*
- *REORIENTATION & OUTFLOW VIA IMPULSIVE ACCELERATION*
- *REORIENTATION & OUTFLOW UNDER CONSTANT LOW-GRAVITY CONDITIONS*
- *THERMAL EFFECTS ON LAD PERFORMANCE*
- THERMAL SUBCOOLING OF LIQUID OUTFLOW

Italicized items must be addressed via flight experiments, however, some information can be obtained via ground based experiments

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY REQUIREMENTS

LIQUID TRANSFER

- *TRANSFER LINE CHILLDOWN*
- *TANK CHILLDOWN WITH SPRAY*
- *NO-VENT FILL*
- *LIQUID ACQUISITION DEVICE (LAD) FILL*
- *LOW-GRAVITY VENTED FILL*

FLUID HANDLING

- *LIQUID DYNAMICS/SLOSH CONTROL*
- *FLUID DUMPING/TANK VENTING AND INERTING*
- EARTH-TO-ORBIT TRANSPORT AS SUBCOOLED LIQUID OR LIQUID/SOLID MIXTURE (SLUSH)

Italicized items must be addressed via flight experiments, however, some information can be obtained via ground based experiments

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY REQUIREMENTS

ADVANCED INSTRUMENTATION

- *QUANTITY GAGING*
- MASS FLOW/QUALITY METERING
- LEAK DETECTION
- LIQUID/VAPOR SENSORS

TANK STRUCTURES AND MATERIALS

- COMPOSITE (LIGHT WEIGHT) VACUUM JACKET
- LOW THERMAL CONDUCTIVITY COMPONENTS
- LOW PRESSURE TANKAGE
- CONTAMINATION/DEGRADATION OF LIQUID ACQUISITION DEVICE

Italicized items must be addressed via flight experiments, however, some information can be obtained via ground based experiments

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY, AN INDUSTRY PERSPECTIVE

John R. Schuster

General Dynamics Space Systems Division
San Diego, California

BACKGROUND

TRANSPORTATION MISSIONS	POSSIBLE DATES
• Interim Space Transfer Vehicle (STV)	1998
• Space-Based STV	2001
• Orbital Propellant Depot	2001
• Lunar Base	2005
• Piloted Mars Expedition	2003-2008

SYSTEM DEVELOPER ROLES

- Design/Fabrication
- Engineering Data Base Development
- Performance Modeling
- Environmental Validation
- System Validation

DEVELOPMENT CHALLENGES

- Achieve Adequate Risk Reduction
- Contend with Constraints
  - Available Testing Environments
  - Schedule
  - Budget
  - Institutional Considerations

TECHNOLOGY NEEDS

MISSION CRITICALITY

Technology Category	Interim STV	Space-Based STV	Orbital Depot	Resupply Tanker	Lunar Base	Mars Expedition
• Liquid Storage						
- Thermal Control Systems						
• Degradation of Material		Enhance	Enhance		Enhance	Enable
• Effect of Launch Env. on Thick MLI	Enable	Enable	Enable	Enhance	Enable	Enable
• Combined Foam/MLI Sys.	Enhance			Enhance		
• Para/Ortho Conversion			Enhance		Enhance	Enhance
• Multiple/Coupled VCS			Enhance		Enhance	Enable
- Pressure Control Systems						
• TVS Performance	Enhance	Enhance	Enable	Enhance		Enable
• Fluid Mixing for Stratification Control	Enhance	Enhance	Enable	Enhance		Enable
• Refrigeration/Reliquefaction			Enhance		Enhance	Enable ?
• Liquid Supply						
- Pressurization System Perf.						
• Autogenous	Enhance	Enable	Enable	Enhance	Enable	Enable
• Helium	Enable					
• Mech. (Pumps/Comp.)			Enhance	Enhance	Enhance	Enhance
- Fluid Acquisition						
• Fine Mesh Screen LAD Performance		Enhance ?	Enable	Enable		Enable
• Fluid Settling & Outflow under Low G Conditions	Enhance	Enhance	Enhance	Enhance		Enhance
• Fluid Settling & Outflow under Impulsive Accel.	Enhance	Enhance		Enhance		Enhance
• Impact of Heat Addition on LAD Performance		Enhance	Enhance ?	Enhance		Enhance
• Thermal Subcooling of Liquid Outflow			Enhance	Enhance	Enhance	Enhance

TECHNOLOGY NEEDS (Cont.)

Technology Category	MISSION CRITICALITY: Interim STV	Space-Based STV	Orbital Depot	Resupply Tanker	Lunar Base	Mars Expedition
• Liquid Transfer						
- Transfer Line Chilldown		Enable	Enable	Enhance	Enable	Enable
- Tank Chilldown with Spray		Enable	Enhance			Enhance
- No-Vent Fill		Enable	Enable			Enhance
- LAD Fill		Enhance ?	Enhance			Enhance
- Low G Vented Fill		Enhance	Enhance			Ehnance
- Pump Assist		Enhance	Enhance	Enhance	Enhance	Enhance
• Fluid Handling						
- Liquid Dynamics/Slosh Control	Enhance	Enhance	Enhance	Enhance		Enhance
- Fluid Dumping & Tank Inerting		Enable	Enable	Enhance		Enhance
- Earth-to-Orbit Transport as Subcooled Liquid or Slush	Enhance	Enhance	Enhance	Enhance		Enhance
• Advanced Instrumentation						
- Quantity Gauging	Enhance	Enhance	Enable			Enhance
- Mass Flow/Quality metering			Enhance		Enhance	Enhance
- Leak Detection		Enhance	Enable		Enable	Enable
- Liquid /Vapor Sensors	Enhance	Enable	Enable	Enhance	Enable	Enable
• Tank Structures & Materials						
- Low Thermal Conductivity Components	Enhance	Enhance	Enhance	Enhance	Enhance	
- Low Pressure Tankage	Enhance	Enhance				Enhance
- Composite(Light Weight) Vacuum Jackets	Enhance			Enhance		
- Contamination/Degradation of LAD		Enhance ?	Enhance			Enhance

IN-SPACE EXPERIMENTATION NEEDS

Technology Category	Engineering Data Base	Performance Modeling	Environmental Validation	System Validation	In-Space Testing Req'd
	TESTING OBJECTIVE				
• Liquid Storage				yes	yes
- Thermal Control Systems					
• Degradation of Material	yes		yes		yes
• Effect of Launch Env. on Thick MLI	yes		yes		
• Combined Foam/MLI Sys.	yes	yes	yes		
• Para/Ortho Conversion	yes	yes			
• Multiple/Coupled VCS	yes	yes			
- Pressure Control Systems					
• TVS Performance	yes	yes	yes		yes
• Fluid Mixing for Stratification Control	yes	yes	yes		yes
• Refrigeration/Reliquefaction	yes	yes			
• Liquid Supply				yes	yes
- Pressurization System Perf.					
• Autogenous	yes	yes	yes		yes
• Helium	yes	yes	yes		yes
• Mech. (Pumps/Comp.)	yes	yes			
- Fluid Acquisition					
• Fine Mesh Screen LAD Performance	yes	yes	yes		yes
• Fluid Settling & Outflow under Low G Conditions	yes	yes	yes		yes
• Fluid Settling & Outflow under Impulsive Accel.	yes	yes	yes		yes
• Impact of Heat Addition on LAD Performance	yes	yes			
• Thermal Subcooling of Liquid Outflow	yes	yes			

IN-SPACE EXPERIMENTATION NEEDS (Cont.)

Technology Category	TESTING OBJECTIVE: Engineering Data Base	Performance Modeling	Environmental Validation	System Validation	In-Space Testing Req'd
• Liquid Transfer				yes	yes
- Transfer Line Chilldown	yes	yes	yes		yes
- Tank Chilldown with Spray	yes	yes	yes		yes
- No-Vent Fill	yes	yes	yes		yes
- LAD Fill	yes	yes	yes		yes
- Low G Vented Fill	yes	yes	yes		yes
- Pump-Assist	yes	yes			
• Fluid Handling				yes	yes
- Liquid Dynamics/Slosh Control	yes	yes	yes		yes
- Fluid Dumping & Tank Inerting	yes	yes	yes		yes
- Earth-to-Orbit Transport as Subcooled Liquid or Slush	yes	yes			
• Advanced Instrumentation				yes	yes
- Quantity Gauging	yes	yes	yes		yes
- Mass Flow/Quality metering	yes	yes			
- Leak Detection	yes	yes			
- Liquid /Vapor Sensors	yes	yes			
• Tank Structures & Materials					
- Low Thermal Conductivity Components	yes	yes	yes		
- Low Pressure Tankage	yes		yes		
- Composite(Light Weight) Vacuum Jackets	yes	yes			
- Contamination/Degradation of LAD	yes				

OBSERVATIONS

- BOTTOM LINE IS RISK REDUCTION
  - Testing and validation methods must be affordable
  - Test results must be timely to support development schedules
- UNIVERSAL PROBLEM
  - Mission planners awed by development challenges
    - Feasibility evaluations become prolonged
    - IOC dates slip
  - Missions too weakly supported to exert technology pull
    - Technology development is slowed
    - Technology development requires long-term commitment
    - In-space testing can be expensive
- MISSION PLANNERS AND TECHNOLOGISTS NEED TO GET IN STEP
  - Link technology development to program milestones
  - Begin technology development early
  - Achieve synergism
    - Programs will "pull" technology
    - Technology advances will "push" programs

4.2 PROPULSION

LOW THRUST PROPULSION SPACE EXPERIMENTS

J. R. STONE

NASA HEADQUARTERS
OFFICE OF AEROSPACE SCIENCE & TECHNOLOGY
PROPULSION, POWER & ENERGY DIVISION

INTRODUCTION/BACKGROUND

- THE NASA LOW THRUST PROPULSION PROGRAM PROVIDES THE TECHNOLOGY FOR ADVANCED ON-BOARD PROPULSION FOR FUTURE SPACE SYSTEMS:
  - SPACECRAFT
  - PLATFORMS
  - TRANSPORTATION VEHICLES
- LOW THRUST PROPULSION TECHNOLOGIES
  - CHEMICAL: HYDROGEN/OXYGEN
STORABLES
  - ELECTRIC: AUXILIARY
PRIMARY

MISSION APPLICATIONS

- ORBIT TRANSFER
  - SATELLITE PLACEMENT/RETURN
  - LOGISTICS
- STATIONKEEPING
  - DRAG & SOLAR PRESSURE
  - EPHEMERIS CONTROL

IMPACT OF LOW THRUST PROPULSION TECHNOLOGY ADVANCEMENT

- MASS SAVINGS FOR
  - SPACECRAFT
  - PLATFORMS
  - VEHICLES

TECHNOLOGY NEEDS/OPPORTUNITIES

- 1-kW CLASS, STORABLE PROPELLANT ARCJET FOR APPLICATIONS SUCH AS COMMUNICATIONS SATELLITE STATIONKEEPING
  - LONG LIFE
  - HIGH DEGREE OF COMMONALITY W. S-O-A SYSTEMS
  - MINIMAL IMPACT ON OTHER SPACECRAFT SYSTEMS/SUBSYSTEMS
- MULTIPROPELLANT RESISTOJETS FOR SPACE STATION FREEDOM AND TENDED PLATFORMS
  - LONG LIFE
  - MINIMIZE LOGISTICS REQUIREMENTS
  - MINIMAL IMPACT ON OTHER SPACECRAFT SYSTEMS/SUBSYSTEMS
- INTEGRATED AUXILIARY PROPULSION FOR LAUNCH & TRANSFER VEHICLES
  - SAVE MASS BY USING RESIDUAL PRIMARY PROPELLANTS
  - SIMPLIFY LOGISTICS (MINIMIZE NUMBER OF FLUIDS HANDLED)
- HIGH POWER ELECTRIC PROPULSION FOR LUNAR/PLANETARY EXPLORATION AND CARGO VEHICLES
  - VERY LONG LIFE, HIGH PERFORMANCE ION & MPD SYSTEMS
  - GROUND FACILITY (POWER/PUMPING/VACUUM) CAPABILITY TO PROVIDE ADEQUATE SPACE SIMULATION NOT ESTABLISHED

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- ADDRESS CRITICAL CRITICAL CONCERNS OF POTENTIAL USERS OF ADVANCED PROPULSION TECHNOLOGY
  - PLUME CONTAMINATION AND PERFORMANCE IMPACTS (BOTH CHEMICAL AND ELECTRIC PROPULSION)
  - ELECTROMAGNETIC INTERFERENCE (CONDUTED AND RADIATED)
  - SPACECRAFT CHARGING
- VALIDATE PERFORMANCE AND LIFE TEST RESULTS FROM GROUND SIMULATION FACILITIES
- MINIMIZE RISK FOR POTENTIAL USERS BY PROVIDING INITIAL DEMONSTRATION OF ADVANCED TECHNOLOGY

SUMMARY/RECOMMENDATIONS

- HIGHEST PRIORITY IS TO CONTINUE TO DEVELOP THE ARCJET FLIGHT TEST OPPORTUNITY ON A COMMERCIAL COMMUNICATIONS SATELLITE
- VERIFY IN SPACE THE VALIDITY OF COMUTATIONAL PREDICTIONS AND GROUND-TEST ASSESSMENTS OF PLUME IMPACTS
- VALIDATE THE ADEQUACY OF GROUND TEST FACILITIES FOR HIGH-POWER ELECTRIC PROPULSION TESTS
- ASSESS THE MERIT OF DEVELOPING A TESTBED CAPABILITY FOR PROPULSION, PROBABLY AS A COMBINED FACILITY APPLICABLE TO OTHER ADVANCED TECHNOLOGIES, SUCH AS POWER

KEY PROPULSION TECHNOLOGIES FOR IN-SPACE EXPERIMENTS

JAMES H. KELLEY

JPL

INTRODUCTION / BACKGROUND

- TWO KEY PROPULSION TECHNOLOGIES NEED FLIGHT DATA
  - SOLAR ELECTRIC PROPULSION (SEP)
    - Xe-ION IN PARTICULAR
  - ROCKET EXHAUST PLUME TECHNOLOGY
- BOTH TECHNOLOGIES WILL DRAMATICALLY AFFECT DESIGNS AND PLANNING FOR FUTURE SPACECRAFT AND MISSIONS
- SEP WOULD BE WIDELY USED WERE IT NOT FOR:
  - DEVELOPMENT COST / RISK
  - UNKNOWNS REGARDING IN-SPACE BEHAVIOR
  - LACK OF FLIGHT EXPERIENCE
- ROCKET EXHAUST PLUMES (ESPECIALLY BIPROPELLANT ACS THRUSTERS) CAN DEGRADE S/C PERFORMANCE THROUGH:
  - FORCES AND MOMENTS
  - HEATING
  - CONTAMINATION

TECHNOLOGY NEEDS

- DEVELOPMENT AND INTEGRATION OF COMPLETE SEPS SYSTEM
  - Xe ION ENGINE
  - POWER PROCESSOR
  - CONTROLER
  - LIGHT WEIGHT SOLAR ARRAY
- DEMONSTRATION OF PERFORMANCE AND LIFE
  - S/C CHARGING ISSUES
  - PLASMA EFFECTS ON SOLAR ARRAY
  - ENGINE LIFE AND PERFORMANCE

TECHNOLOGY NEEDS

- RELIABLE, VALIDATED, PREDICTIVE MODELS OF:
  - CONTAMINANT GENERATION
  - NOZZLE AND PLUME FLOW FIELDS
  - PLUME / SURFACE INTERACTIONS
  - CONTAMINANT PROPERTIES

- PRESENT MODELS ARE DEFICIENT
  - KNOWN TO CONTAIN ERRONEOUS ASSUMPTIONS WHERE BASIC PHYSICAL UNDERSTANDING IS MISSING

TECHNOLOGY NEEDS
(CONTINUED)

- DEVELOPMENT OF PREDICTIVE PLUME CAPABILITY REQUIRES

  IMPROVED UNDERSTANDING OF COMBUSTIION IN PULSED ROCKET ENGINES

  DEVELOPMENT OF NOZZLE FLOW FIELD CODES FOR FULLY TRANSIENT, VISCOUS, REACTING FLOWS

  DEVELOPMENT AND VALIDATION OF CODES TO PREDICT RAREFIED PLUME FLOW FIELDS

- COLLECTION OF QUALITY EXPERIMENTAL DATA IS A FORMIDIBLE TASK

  IMPROVED DIAGNOSTICS NEEDED

IN-SPACE EXPERIMENTATION NEEDS / VOIDS

- SEP-INDUCED PLASMA / SPACECRAFT INTERACTIONS CAN ONLY BE EVALUATED IN SPACE

  SPACECRAFT CHARGING EFFECTS

  PLASMA-INDUCED LEAKAGE CURRENTS ON SOLAR ARRAY

- SERT FLIGHT TESTS OF MERCURY ION ENGINES IN THE 1960s REVEALED THAT ENGINE LIFE CAN BE LIMITED BY MECHANISMS UNIQUE TO SPACE (i.e., ZERO G)

  IN-SPACE DEMONSTRATION REQUIRED TO PROVIDE ACCEPTABLE RISK FOR USERS OF SEP!

IN-SPACE EXPERIMENTATION NEEDS / VOIDS

- GROUND-BASED TESTS CAN NOT SIMULATE THE EXPANSION OF A ROCKET EXHAUST PLUME INTO A SPACE ENVIRONMENT

  PLUME DENSITIES AS LOW AS 10 MOLECULES/CC ARE OF INTEREST

  DENSITY OF BACKGROUND IN THE BEST SPACE SIMULATORS IS MORE THAN 10 ORDERS OF MAGNITUDE TOO HIGH

- CONTAMINANT (i.e., DROPLET) GENERATION AND TRANSPORT IS ALTERED BY GRAVITY IN GROUND TESTS

IN-SPACE EXPERIMENTATION NEEDS / VOIDS
(CONTINUED)

- DATA COLLECTED IN SPACE TO DATE MONITORS CONTAMINATION BUT DOES NOT:
  - UNIQUELY IDENTIFY SOURCE
  - ADEQUATELY CHARACTERIZE CONTAMINANT PROPERTIES
  - ALLOW DETERMINATION OF WHAT PROBLEMS EXIST IN PREDICTIVE METHODS, e.g.;
    - INCORRECT MODEL OF CONTAMINANT GENERATION?
    - INCORRECT MODEL OF RAREFIED FLOW FIELD?
    - INADEQUATE MODEL OF SURFACE INTERACTIONS?

IN-SPACE TECHNOLOGY EXPERIMENTS

IN

PROPULSION:

THE ROLE OF UNIVERSITIES

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INTRODUCTION / BACKGROUND

- UNIVERSITY PARTICIPATION IN SPACE EXPERIMENTATION REQUIRES INNOVATION
- TRADITIONAL UNIVERSITY RESEARCH ROLES NOT EFFECTIVE IN SPACE EXPERIMENTATION
- LEAD TIMES FOR SPACE EXPERIMENTS CAN EXCEED STUDENT DEGREE PROGRAMS
- COMPLEXITY OF SPACE EXPERIMENTATION REQUIRES GROUP PARTICIPATION
- IMPORTANT TO GET FACULTY ATTENTION/COMMITMENT TO INTERDISCIPLINARY RESEARCH

TECHNOLOGY ISSUES

- PROPULSION PERTAINS TO ALL SPACE MISSIONS
- DIVERSE MISSION REQUIREMENTS DEFINE NEED FOR BROAD RANGE OF PROPULSION SYSTEMS
  - Sizes
  - Concepts
  - Capabilities
- BOTH PROPULSION AND SPACE EXPERIMENTATION ARE STRONGLY MULTIDISCIPLINARY
- EMPHASIS ON SAFETY/PACKAGING/INTEGRATION REQUIRES DIVERSE EXPERTISE BEYOND SPECIFIC EXPERIMENT
- IN-SPACE EXPERIMENTATION REQUIRES LONG LEAD TIMES
  - May Exceed Degree Lengths

ATTRIBUTES OF UNIVERSITIES FOR IN-STEP

- PRIMARY SOURCE OF NEW TALENT TO NASA/INDUSTRY

- POTENTIAL UNIVERSITY CONTRIBUTIONS INCLUDE:
  - Get Graduates Aware/Interested in Space Experimentation
  - Impact Curricula to Provide Graduates With Proper Background
  - Bring Expertise of Faculty to Bear on Fundamental Problems
  - Provide Direct Input in Terms of Research Findings

- UNIVERSITY RESEARCH HAS HISTORICALLY FOCUSSED ON:
  - Independent Researchers
  - Simple Experiments
  - Providing In-Depth Understanding From Detailed Measurements

- IN-STEP REQUIRES:
  - Group Participation
  - Single Shot Experiments
  - In-Depth Understanding from Limited Information

SUMMARY / RECOMMENDATIONS

- UNIVERSITIES MUST FUNCTION AS SUB-ELEMENTS OF NASA/INDUSTRY GROUPS
- TRADITIONAL ROLE OF FACULTY AS INDEPENDENT INVESTIGATORS MUST BE MODIFIED
- ATTEMPTS SHOULD BE MADE TO KEEP FACULTY INVOLVED IN SIMPLE, FUNDAMENTAL EXPERIMENTS
- IMPORTANT TO INVOLVE UNIVERSITIES TO IMPACT GRADUATES' AWARENESS, INTEREST, AND EXPERTISE
- IN-SPACE ROLE OF STUDENTS/FACULTY IS EXPECTED DOWNSTREAM
- FACULTY/UNIVERSITIES NEED ENCOURAGEMENT TO PARTICIPATE IN INTERDISCIPLINARY PROGRAMS

4.3 FLUID PHYSICS

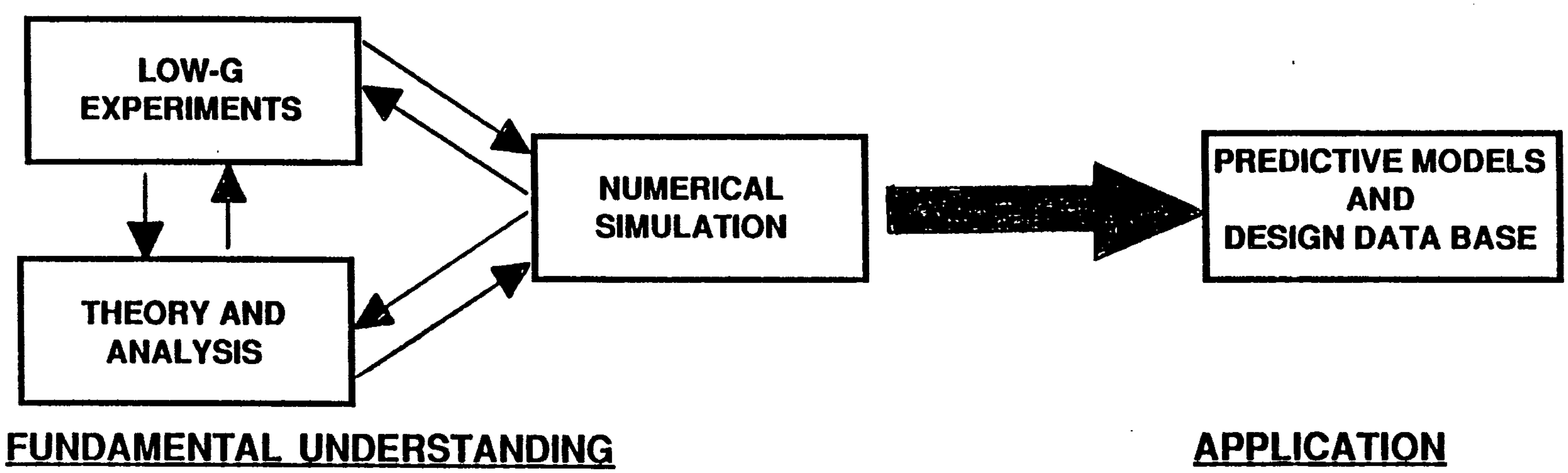
FLUID PHYSICS

Jack A. Salzman
NASA Lewis Research Center

OBJECTIVE

ENHANCE THE FUNDAMENTAL UNDERSTANDING OF FLUID BEHAVIOR AND DYNAMICS IN A REDUCED GRAVITY ENVIRONMENT TO ENABLE THE DEVELOPMENT OF ADVANCED SPACE SYSTEMS.

PROCESS



APPROACH

SYSTEMATIC AND STRUCTURED PROGRAM OF CONDUCTING LOW-GRAVITY FLUIDS EXPERIMENTS GUIDED BY THEORETICAL ANALYSES AND NUMERICAL SIMULATION TO PROGRESSIVELY BUILD UNDERSTANDING AND DATA BASES

BACKGROUND

- EXTENSIVE LOW-GRAVITY FLUID RESEARCH PROGRAM DURING 1960'S AND EARLY 1970'S
- RANGE OF CRITICAL FLUID MANAGEMENT ISSUES/PROBLEMS IDENTIFIED AND ADDRESSED
  - FOCUSED MISSION/SYSTEM DRIVEN RESEARCH
  - DEPTH OF BASIC UNDERSTANDING LIMITED TO SPECIFIC GOALS SET FOR EACH MISSION
  - CRITICAL ENABLING FLUID MANAGEMENT FUNCTIONS IN SPACE ACCOMPLISHED
- LOW-GRAVITY FLUIDS RESEARCH IN LATE 1970'S AND EARLY 1980'S AT MAINTENANCE LEVEL
  - CRYOGENIC FLUIDS PROGRAMS
  - PHYSICS AND CHEMISTRY EXPERIMENTS PROGRAM (PACE)
- RENEWED INTEREST WITH NEW MISSION DRIVERS
  - MANY OF THE SAME OLD PROBLEMS
  - NEW SPECIFIC PROBLEMS BUT SAME BASIC FLUID PROCESSES

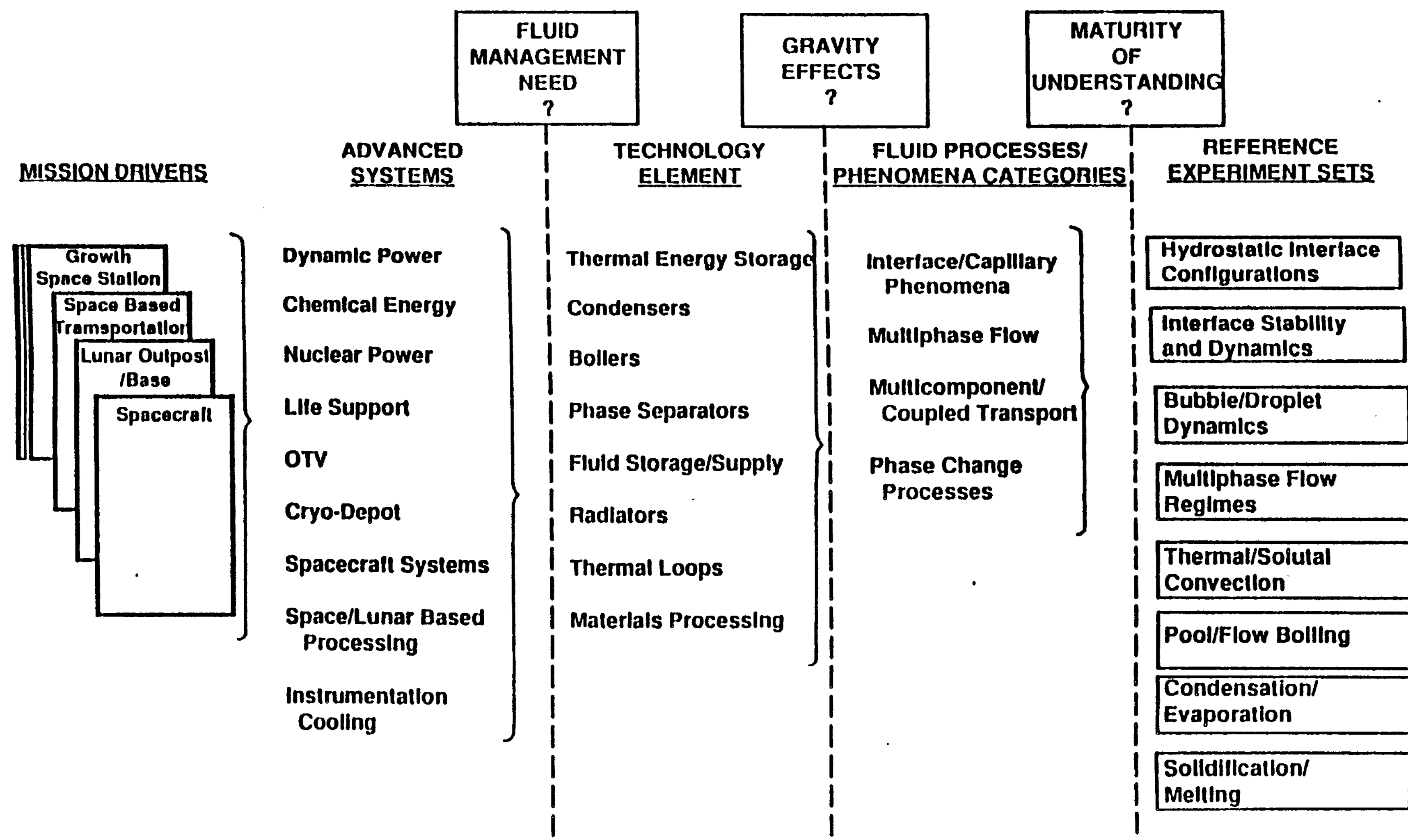
STATUS

PREDICTIVE MODELS FOR LOW-GRAVITY FLUID BEHAVIOR AND PROCESSES ARE INADEQUATE, INACCURATE, AND POTENTIALLY MISLEADING

FLUID MGMT & PROPULSION | IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP | FLUID PHYSICS

DECEMBER 6-9, 1988

GENERAL PLANNING MODEL



REFERENCE EXPERIMENT SET OBJECTIVES

ESTABLISH AND VERIFY ANALYTICAL/NUMERICAL MODELS TO PREDICT:

HYDROSTATIC INTERFACE CONFIGURATIONS

THE BULK LIQUID LOCATION AND THE CONFIGURATION OF THE EQUILIBRIUM LIQUID-GAS INTERFACE AS A FUNCTION OF FLUID PROPERTIES, VESSEL GEOMETRY AND SIZE, GRAVITY LEVEL, AND SYSTEM INITIAL CONDITIONS

INTERFACE STABILITY AND DYNAMICS

THE RESPONSE OF A REDUCED-GRAVITY LIQUID-VAPOR INTERFACE TO MECHANICAL AND THERMAL DISTURBANCES AND ITS EFFECTS ON BULK LIQUID MOTION

BUBBLE/DROPLET DYNAMICS

THE BUOYANCY AND/OR THERMALLY DRIVEN MOTION OF SINGLE BUBBLE/ DROPLET UNDER REDUCED GRAVITY CONDITIONS AND THE INTERACTIONSBETWEEN MULTIPLE BUBBLES/DROPLETS INCLUDING COALESCENCE/BREAKUP

MULTIPHASE FLOW REGIMES

THE FLOW REGIME PATTERNS & CHARACTERISTICS GENERATED BY THE FORCED ADIABATIC FLOW OF LIQUID-VAPOR OR IMMISCIBLE LIQUID MIXTURES THROUGH CONDUITS AND FITTINGS AS A FUNCTION OF FLUIDPROPERTIES, FLOW RATES, CONDUIT/FITTING GEOMETRY AND SIZE, AND GRAVITY LEVEL

THERMAL/SOLUTAL CONVECTION

THE HEAT AND MASS TRANSFER GENERATED BY BUOYANCY DRIVEN FLOWS RESULTING FROM THERMAL AND/OR CONCENTRATION GRADIENTS UNDER REDUCED GRAVITY CONDITIONS.

POOL/FLOW BOILING

THE ONSET OF NUCLEATE BOILING AND SUBSEQUENT BUBBLE DYNAMICS AS A FUNCTION OF SYSTEM SATURATION SUBCOOLING, HEAT FLUX, FLUID PROPERTIES, HEATER GEOMETRY, AND GRAVITY LEVEL FOR BOTH STAGNANT AND LIQUID FLOW CONDITIONS.

CONDENSATION/EVAPORATION

THE CONDITIONS FOR CONDENSATION/EVAPORATION OF LIQUID AT LIQUID-VAPOR INTERFACES AND ITS EFFECTS ON INTERFACE STABILITY/DYNAMICS UNDER LOW-GRAVITY CONDITIONS FOR BOTH STAGNANT AND VAPOR FLOW CONDITIONS

SOLIDIFICATION/MELTING

THE DYNAMIC BEHAVIOR OF THE SOLID-FLUID FRONT DURING SOLIDIFICATION AND/OR MELTING UNDER LOW-GRAVITY CONDITIONS WITH SPECIAL EMPHASIS ON VOID FORMATION AND DYNAMICS DUE TO VOLUME CHANGES.

IN-SPACE EXPERIMENT DESIGN OPTIONS

- ALL EXPERIMENT REFERENCE SET OBJECTIVES CAN BE ACHIEVED THROUGH TWO APPROACH OPTIONS
  - SEVERAL (≥7) SPECIALIZED SETS OF EXPERIMENT HARDWARE WITH LIMITED COMPLEXITY/CAPABILITIES
  - TWO OR THREE SETS OF FACILITY CLASS HARDWARE
- CHOICE OF APPROACH DICTATED BY
  - MANIFEST OPPORTUNITIES
  - BASIC IN-STEP PHILOSOPHIES ON PROGRAM STRUCTURE (E.G., INDIVIDUAL EXPERIMENTER PROVIDED HARDWARE VS NASA FURNISHED HARDWARE FOR EXPERIMENT TEAMS)
  - EXISTENCE OF CRITICAL TIMELINE FOR DATA ACQUISITION

ONE POSSIBLE SPACE FACILITY APPROACH

- INITIALLY IMPLEMENT ADIABATIC MULTIPHASE FLOW CLOSED-LOOP SYSTEM
  - SINGLE LIQUID-GAS PAIR
  - STRAIGHT CONDUIT TEST SECTION
  - LIMITED DIAGNOSTICS
- FIRST ADD CAPABILITIES FOR
  - ISOLATED TEST SECTION WITH HEATERS FOR POOL BOILING EXPERIMENT
  - MULTIPLE LIQUID-GAS PAIRS
  - INCREASED DIAGNOSTICS
- NEXT ADD CAPABILITIES FOR
  - FLOW BOILING EXPERIMENTS
  - FLOW THROUGH FITTINGS
  - INCREASED DIAGNOSTICS
- NEXT ADD CAPABILITIES FOR
  - FLOW CONDENSATION EXPERIMENTS
  - MULTIPLE BUBBLE/DROP COALESCENCE & MIGRATION EXPERIMENTS

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Fluid Mngmnt. Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP December 6-9, 1988	Fluid Physics

LOW-G INTERFACE CONFIGURATIONS, STABILITY, AND DYNAMICS

FRANKLIN T. DODGE

Southwest Research Institute

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP
December 6-9, 1988

BACKGROUND AND GENERAL OBSERVATIONS

Interface configurations, stability, and dynamics have a prominent effect on spacecraft design and operations.

1. Progress in predictive methods (CFD codes) is hampered by lack of understanding of free-surface physics in low gravity (e.g., contact line motion).
2. Interface motions in many cases interact with other systems.
3. For cryogens, interface motions can affect heat transfer, vaporization, and other thermal effects.

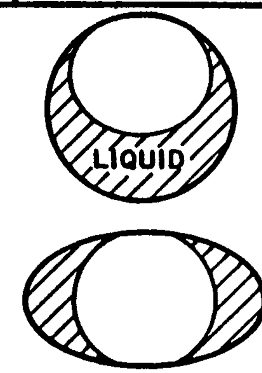
This discussion will focus on:

- Identifying important liquid processes
- technology needed to solve the problems
- required in-space experimentation
- problems caused by lack of predictive understanding

Discussion will use examples of satellites and OTV.

Fluid Mngmnt. Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP December 6-9, 1988	Fluid Physics

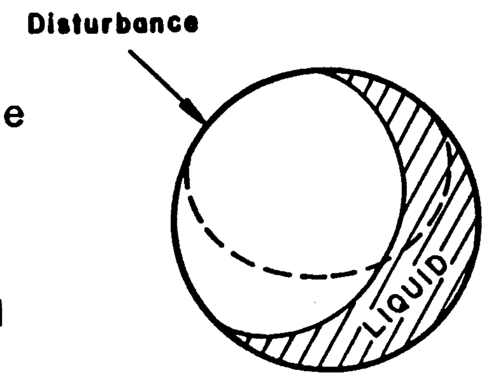
EXAMPLE: Orbiting Satellite



Fluid Process: Interface Configuration

Problem: Since interface locations are unknown, "propellant management devices" are used to insure gas-free liquid. This inceases weight/complexity and decreases reliability.

Technology Need: Predict interface location as a function of tank geometry, fluid properties, tank surface properties, fill level, gravity vector, and history of satellite operations.



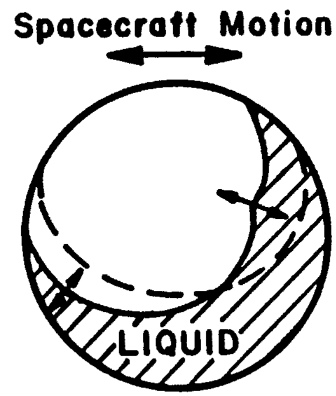
Fluid Process: Interface stability - what disturbance level (satellite motion) will cause an interface to re-locate

Problem: PMD's are used to circumvent the problem. Complexity and weight increase, and reliability decreases.

Technology Need: Accurate prediction of the required acceleration needed to de-stabilize an interface

Fluid Mngmnt. Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP December 6-9, 1988	Fluid Physics

ORBITING SATELLITE (cont'd)



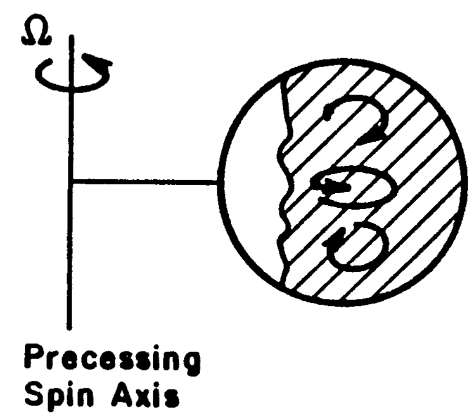
Fluid Process: Interface Dynamics

Problem: Maneuvering sets the liquid in motion; this feeds back disturbances. The maneuver is degraded (Peacekeeper, space telescope, SDI systems, comm. satellites)

Technology Need: Surface tension and contact line dynamics control the liquid motion. Physics of the motion is not understood Motions may not be small. Need to predict motions as a function of tank shape, liquid properties, tank surface properties, fill level, and spacecraft motion. (Current CFD codes are of limited use because of poor surface physics.)

Fluid Mngmnt. Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP December 6-9, 1988	Fluid Physics

EXAMPLE: Spin Stabilized Satellite



Fluid Process: Liquid configuration and motion in a tank spinning about an axis outside the tank, when surface tension is important.

Problem: Liquid motions and viscous dissipation can not be predicted. Spacecraft design is thus very conservative or even abandoned in favor of non-spinners.

Technology Need: Liquid motions do not resemble non-spinning motions (e.g., a free-surface is not necessary). No good theory exists. Ground-based tests are of limited value. Need to predict motions and energy dissipation and the influence of surface physics.

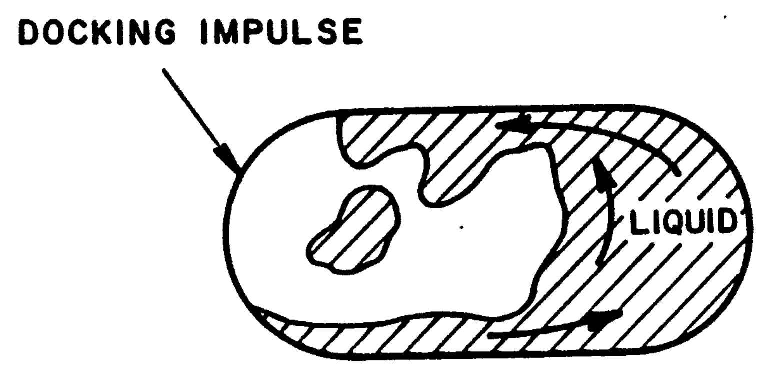
Fluid Mngmnt. Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP December 6-9, 1988	Fluid Physics

EXAMPLE: OTV

Fluid Process: Interface configuration and stability

Problems:
- gas-free liquid transfer
- quantity-gaging - liquid location is unknown so elaborate, heavy, complex, and limited accuracy systems are used.

Technology Need: Accurate prediction of interface location so a simple, reliable, accurate gaging system can be used.



Fluid Process: Interface dynamics and bulk liquid motion.

Problem: Docking causes large impulsive accelerations. The liquid undergoes gross motions which degrade control and increase liquid transfer time.

Technology Need: Validate method (CFD code) to predict large free-surface motions in low-g and the duration of such motions

IN-SPACE EXPERIMENTATION NEEDS

Interface configuration and stability

High-quality reference set of data to verify and guide analytical/numerical models

Interface slosh dynamics

Highly instrumented reference data sets to guide and verify analytical/numerical models (wave shape, natural frequency, forces and moments, nonlinear effects, damping).

Liquid dynamics in spinning tanks

Acquire fundamental understanding to illuminate the physics and guide/validate models

Large amplitude interface motions

Reference data sets to verify numerical models

PRIORITIZATION OF IN-SPACE EXPERIMENTATION

<u>Phase 1</u>

- Interface slosh dynamics
- Liquid dynamics in a spinning tank

<u>Phase 2</u>

- Interface configuration
- Interface stability
- Large interface motions

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IN SPACE TECHNOLOGY EXPERIMENTS WORKSHOP
DECEMBER 6-9, 1988
SUB THEME: FLUID PHYSICS

THE CASE FOR TWO PHASE GAS-LIQUID FLOW EXPERIMENTS IN SPACE

BY

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TWO PHASE FLOW EXPERIMENTS IN SPACE

BACKGROUND

- TWO PHASE FLOW WILL EXIST IN MANY APPLICATIONS IN SPACE
  - RANKIN POWER CYCLE
  - EMERGENCY NUCLEAR COOLING SYSTEMS
  - SPACE STATION THERMAL BUS
  - TRANSFER LINES FOR RESUPPLY OF CRYOGEN TANKS
  - PROJECTED CHEMICAL PROCESSING OPERATIONS

- GRAVITY LEVEL HAS A PROFOUND EFFECT ON THESE FLOWS BECAUSE OF THE EXISTENCE OF FREE INTERFACES

- BASIC FLUID MECHANICAL MODELS WHICH ARE NEEDED TO DESIGN SUCH SYSTEMS AT REDUCED GRAVITY ARE LARGELY NON EXISTENT

- THE PENALTY FOR THIS IGNORANCE IS OVERDESIGN WITH THE COST OF EXTRA WEIGHT TO LIFT TO ORBIT AND POSSIBLE UNSAFE OPERATING CONDITIONS.

- SOUND MODELLING IS NEEDED ALONG WITH CAREFUL SPACE EXPERIMENTS IN ORDER THAT DESIGN METHODS BE AVAILABLE IN THE NEAR FUTURE.

IN SPACE TECHNOLOGY EXPERIMENTS WORKSHOP
DECEMBER 6-9, 1988
SUB THEME: FLUID PHYSICS

TWO PHASE FLOW SPACE EXPERIMENTS

EXAMPLES OF TECHNOLOGY NEEDS RELATED TO TWO PHASE FLOW

A. THE RANKIN CYCLE

- REACTOR/BOILER
    - TWO PHASE FLOW PRESSURE DROP (BOILER FEED PUMP DESIGN)
    - FLOW PATTERN (TWO PHASE FLOW PRESSURE DROP)
    - BUBBLE SIZE (INTERFACIAL AREA AVAILABLE FOR HT TRANSFER)
    - SIZE AND VELOCITY OF LIQUID SLUGS (STABILITY &VIBRATION; LOCAL HEAT TRANSFER COEFFICIENTS)
    - VOID FRACTION (HT TRANSFER COEFF AND HT TRANSFER AREA REQD)
    - BUBBLE COALESCENCE FREQUENCY AND INTERFACIAL WAVE MOTION (TRANSITION TO FILM BOILING AND BURNOUT)

- SEPARATOR
    - INLET FLOW PATTERN

- SEPARATOR-TURBINE TRANSFER LINE
    - PRESSURE DROP DURING ANNULAR FLOW (LINE SIZING)
    - THICKNESS OF CONDENSED FILM (CALC'N OF HEAT LOSS & P)

A. THE RANKIN CYCLE (CONT'D)

- TURBINE
  - DROP SIZE AND VELOCITY (TURBINE PERFORMANCE)
  - DROP DEPOSITION (BLADE DESIGN)
- TURBINE-CONDENSER TRANSFER LINE
  - FLOW PATTERN (STABILITY AND VIBRATION)
  - PRESSURE DROP (LINE SIZING)
- CONDENSER
  - FLOW PATTERN AS GAS AND LIQUID RATIO CHANGE ALONG CONDENSER (CONTROLS HT TRANSF. COEFF AND HEAT TRANSFER AREA)
  - PRESSURE DROP (CYCLE EFFICIENCY)

B. COOLDOWN OF CRYOGEN TRANSFER LINE

- DURING COOLDOWN TWO PHASE FLOW TAKES PLACE. PRESSURE DROP IS MUCH LARGER THAN FOR SINGLE PHASE FLOW AND CAPACITY OF THE LINE IS SMALLER.
- FLOW PATTERN IS IMPORTANT TO PREDICTING THE HT TRANSFER AND MUST BE KNOWN TO DESIGN THE TANK STORAGE DISTRIBUTORS.

TWO PHASE FLOW SPACE EXPERIMENTS WHICH ARE NEEDED

APPROACH:

- PHYSICAL AND MATHEMATICAL MODELLING IS UNDERTAKEN TO IDENTIFY THE FUNDAMENTAL PROCESSES CONTROLLING THE PHENOMENA
- SPACE EXPERIMENTS ARE DESIGNED TO TEST THESE UNDERLYING PREMISES BUT NOT TO OBTAIN EMPIRICAL CORRELATIONS
- MODELS ARE MODIFIED BASED ON THE PHYSICAL INSIGHTS OBTAINED FROM THE EXPTS. SUBSEQUENT RUNS IN SPACE UNDER DIFFERENT FLOW CONDITIONS, FLUID PROPERTIES OR GEOMETRY ARE USED TO TEST THE GENERALITY OF THE MODEL.

SOME EXPERIMENTAL SYSTEMS:

A. *THE ISOTHERMAL LOOP FOR MACRO MEASUREMENTS*

THIS SYSTEM IS TO BE DESIGNED TO FLOW GAS/LIQUID PAIRS OVER A WIDE RANGE OF RATES IN SEVERAL LINE DIAMETERS, INSTRUMENTED TO MEASURE FLOW PATTERN, TIME VARYING PRESSURE GRADIENT, CROSSECTIONAL AVERAGE VOIDS AND LOCAL FILM THICKNESS DURING ANNULAR FLOW. MUST BE SUITABLE FOR SEVERAL DIFFERENT FLUIDS TO STUDY THE EFFECT OF FLUID PROPERTIES. LOW PRESSURE SYSTEM. RELATIVELY SIMPLE INSTRUMENTATION AND DATA ACQUISITION SYSTEM.

IN SPACE TECHNOLOGY EXPERIMENTS WORKSHOP
DECEMBER 6-9, 1988
SUB THEME: FLUID PHYSICS

TWO PHASE FLOW SPACE EXPERIMENTS WHICH ARE NEEDED (CONTINUED)

B *THE ISOTHERMAL LOOP FOR MICRO MEASUREMENTS*

A CLOSED LOOP EQUIPPED WITH A LASER VELOCIMETER SYSTEM AND INSTRUMENTATION TO MEASURE BUBBLE AND DROP SIZE AND VELOCITY . INSTRUMENTATION IS MORE COMPLEX AND SOME DEVELOPMENT WILL BE NECESSARY TO ADAPT EXISTING INSTRUMENTS FOR SPACE.

C. *BOILING/CONDENSATION LOOP*

A CLOSED LOOP SYSTEM TO PERMIT THE STUDY OF TWO PHASE FLOW IN CONDITIONS OF CONDENSATION AND BOILING. THIS WILL INCLUDE LOCAL HEATX FLUX PROBES AS WELL AS PROBES FOR MACROSCOPIC TWO PHASE FLOW MEASUREMENTS.

NEEDED EMPHASIS:

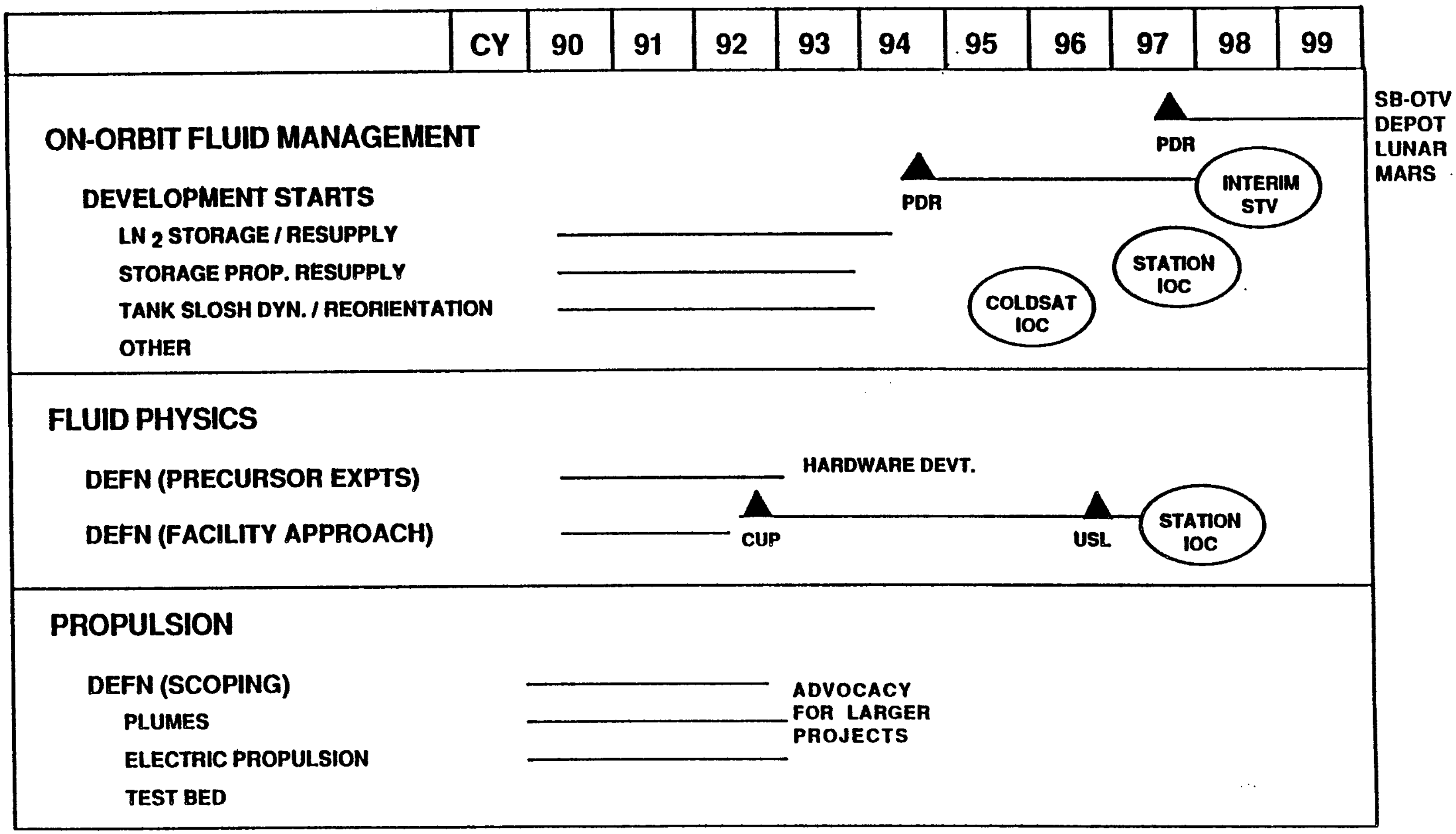
EXPERIMENTS MUST BE DESIGNED AND EQUIPMENT INSTRUMENTED TO REVEAL UNDERLYING MECHANISM OF THE FLOW. OBTAINING DATA FOLLOWED BY EMPIRICAL CORRELATION WILL BE OF LIMITED USEFULNESS.

FLUID MANAGEMENT & PROPULSION SYSTEMS CRITICAL TECHNOLOGY REQUIREMENTS

LYNN ANDERSON
LEWIS RESEARCH CENTER

Fluid Mgmt & Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Theme Summary

PROPOSED ROADMAP



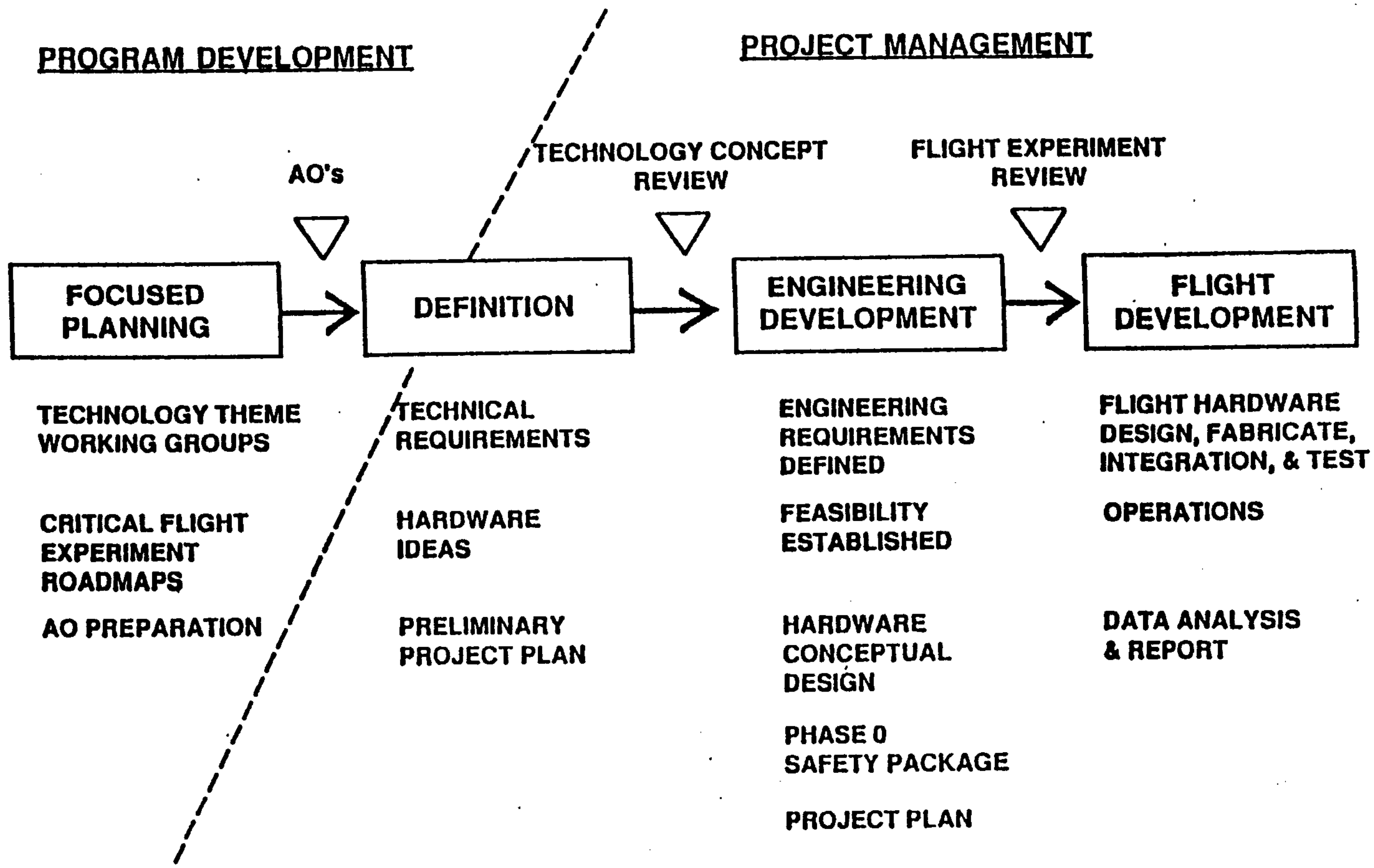
Fluid Mgmt & Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	Theme Summary

NASA Lewis Research Center

SPACE EXPERIMENTS DIVISION

SFSD Space Flight Systems Directorate

OAST IN-SPACE TECHNOLOGY PROGRAM PHASES



WORKSHOP SPEAKERS

On-Orbit Fluid Mgmt	John Aydelott John Schuster Leon Hastings	NASA LeRC General Dynamics NASA MSFC
Fluid Physics	Jack Salzman Dr. Franklin Dodge Dr. A. E. Dukler	NASA LeRC Southwest Res. Inst. U. Houston
Propulsion	James A. Kelley James Stone Dr. Charles Merkle	Jet Propulsion Lab OAST/RP Pennsylvania State U.

PARTICIPANTS (ROUGHLY)

	GOVERNMENT	INDUSTRY	UNIVERSITY
ON-ORBIT FLUID MGMT.	LeRC / COLDSAT MSFC JSC KSC	GENERAL DYNAMICS MARTIN MARIETTA BOEING AEROSPACE McDONNELL DOUGLAS LOCKHEED	U. TENN.
FLUID PHYSICS	LeRC / MICROGRAV.	SW RESEARCH INST. BATTELLE NW TELEDYNE BROWN FOSTER MILLER AM. SPACE TECH. EG&G IDAHO	U. HOUSTON U. TENN. U. MICHIGAN
PROPULSIOON	LeRC / ELECTRIC JPL / PLANETARY LeRC / CHEMICAL SPACE STATION	GRUMMAN ROCKETDYNE ROCKET RES. WESTINGHOUSE	PENN. STATE PRINCETON

ON-ORBIT FLUID MANAGEMENT THEME ELEMENT

POTENTIAL THRUSTS:

- PROVIDE ENHANCING TECHNOLOGY FOR SPACE STATION FREEDOM ORBITAL MANEUVERING VEHICLE, INTERIM STV, CO-ORBITING PLATFORM, AND COLD-SAT

AND / OR PROVIDE ENABLING TECHNOLOGY FOR ORBITAL DEPOT, RESUPPLY TANKER, LUNAR BASE, MARS EXPEDITION

CRITICAL TECHNOLOGIES

- LIQUID STORAGE
- LIQUID SUPPLY
- LIQUID TRANSFER
- FLUID HANDLING
- INSTRUMENTATION

AUDIENCE PRIORITIES

1. FLUID TRANSFER
2. MASS GAUGING
3. TVS / MIXING
   LAD PERFORMANCE
   FLUID DUMPING / TANK INERTING
4. LIQUID DYNAMICS / SLOSH
5. AUTOGENOUS PRESSURIZATION
   LONG TERM STORAGE

REPRESENTATIVE PROJECTS

- LIQUID NITROGEN STORAGE & SUPPLY EXPT - DEVT
- STORAGE PROPELLANT RESUPPLY
- TANK SLOSH DYNAMICS & LIQ. REORIENTATION

SPEEDY DEFN & DEVT

REPRESENTATIVE PROJECTS

- **LIQUID NITROGEN STORAGE AND SUPPLY EXPERIMENT**

  - ENHANCE ABILITY TO PROVIDE CRYO HEAT SINK FOR SPACE STATION EXPERIMENTS AND LAB FREEZER OPERATION FOR SPECIMEN PRESERVATION. REDUCE ANNUAL LIFE SUPPORT SYSTEM RESUPPLY TANKAGE WEIGHT TRANSPORTED TO STATION. SUPPORT DEVELOPMENT OF ISTV AND COLD-SAT.

    - CARGO EXPT
    - LN_2 STORAGE DEWAR
    - PASSIVE TVS, MIXER
    - LIQUID ACQUISITION DEVICE
    - STORAGE & SUPPLY IN LOW GRAVITY
    - VENT TANK & DUMP OVERBOARD
    - N_2 & HE PRESSURANTS
    - GAGING INSTRUMENTATION

- **STORABLE PROPELLANT RESUPPLY EXPERIMENT**

  - ENHANCE ABILITY FOR ON-ORBIT SERVICING OF OMV AND CO-ORBITING PLATFORM. SUPPORT OTHER BI-PROP USERS AND DEVELOPMENT OF COLD-SAT.

    - CARGO ON MIDDECK EXPT
    - REFEREE FLUID
    - FILL STORABLE PROP. TANK
    - LAD PERFORMANCE & FILL
    - TANK VENTING
    - MASS GAUGING

- **TANK SLOSH DYNAMICS AND LIQUID REORIENTATION**

  - ENHANCE OMV AND ISTV PERFORMANCE BY INCREASING DYNAMIC STABILITY, PROPELLANT UTILIZATION. REDUCE REQUIRED DESIGN MARGINS.

    - MIDDECK EXPERIMENT
    - REFEREE FLUID
    - MULTIPLE TANKS (SIZE, SHAPE)
    - SLOSH & REORIENT UNDER IMPOSED LOW-G
    - VIDEO

CRITICAL IN-SPACE TECHNOLOGY NEEDS

- EFFECT OF LAUNCH ENVIRONMENT ON THICK MULTILAYVER INSULATION

• LONG TERM SPACE ENVIRONMENT EFFECTS ON INSULATION (DEBRIS, MICROMETEROIDS AND ATOMIC OXYGEN)

- COMBINED EARTH/ORBIT INSULATION
- COOLING ENHANCEMENT PROVIDED BY PARA-TO-ORTHO CONVERSION
- MULTIPLE/COUPLED VAPOR COOLED SHIELDS

• THERMODYNAMIC VENT SYSTEM PERFORMANCE

• FLUID MIXING FOR STRATIFICATION CONTROL

- REFRIGERATION/LIQUEFACTION SYSTEM DEMONSTRATION (INCLUDING CONDENSATE COLLECTION)

• AUTOGENOUS (INCLUDING PARA/ORTHO COMPOSITION) PRESSURIZATION SYSTEM

• HELIUM SUPPLY/PRESSURIZATION

- MECHANICAL TRANSFER (PUMPS/COMPRESSORS)

• FINE MESH SCREEN LIQUID ACQUISITION DEVICE (LAD) EXPULSION EFFICIENCY

• REORIENTATION & OUTFLOW VIA IMPULSIVE ACCELERATION

• REORIENTATION & OUTFLOW UNDER CONSTANT LOW-GRAVITY CONDITIONS

• THERMAL EFFECTS ON LAD PERFORMANCE

- THERMAL SUBCOOLING OF LIQUID OUTFLOW

• TRANSFER LINE CHILLDOWN

• TANK CHILLDOWN WITH SPRAY

• NO-VENT FILL

• LIQUID ACQUISITION DEVICE (LAD) FILL

• LOW-GRAVITY VENTED FILL

• LIQUID DYNAMICS/SLOSH CONTROL

• FLUID DUMPING/TANK VENTING AND INERTING

- EARTH-TO-ORBIT TRANSPORT AS SUBCOOLED LIQUID OR LIQUID/SOLID MIXTURE (SLUSH)

• QUANTITY GAGING

- MASS FLOW/QUALITY METERING

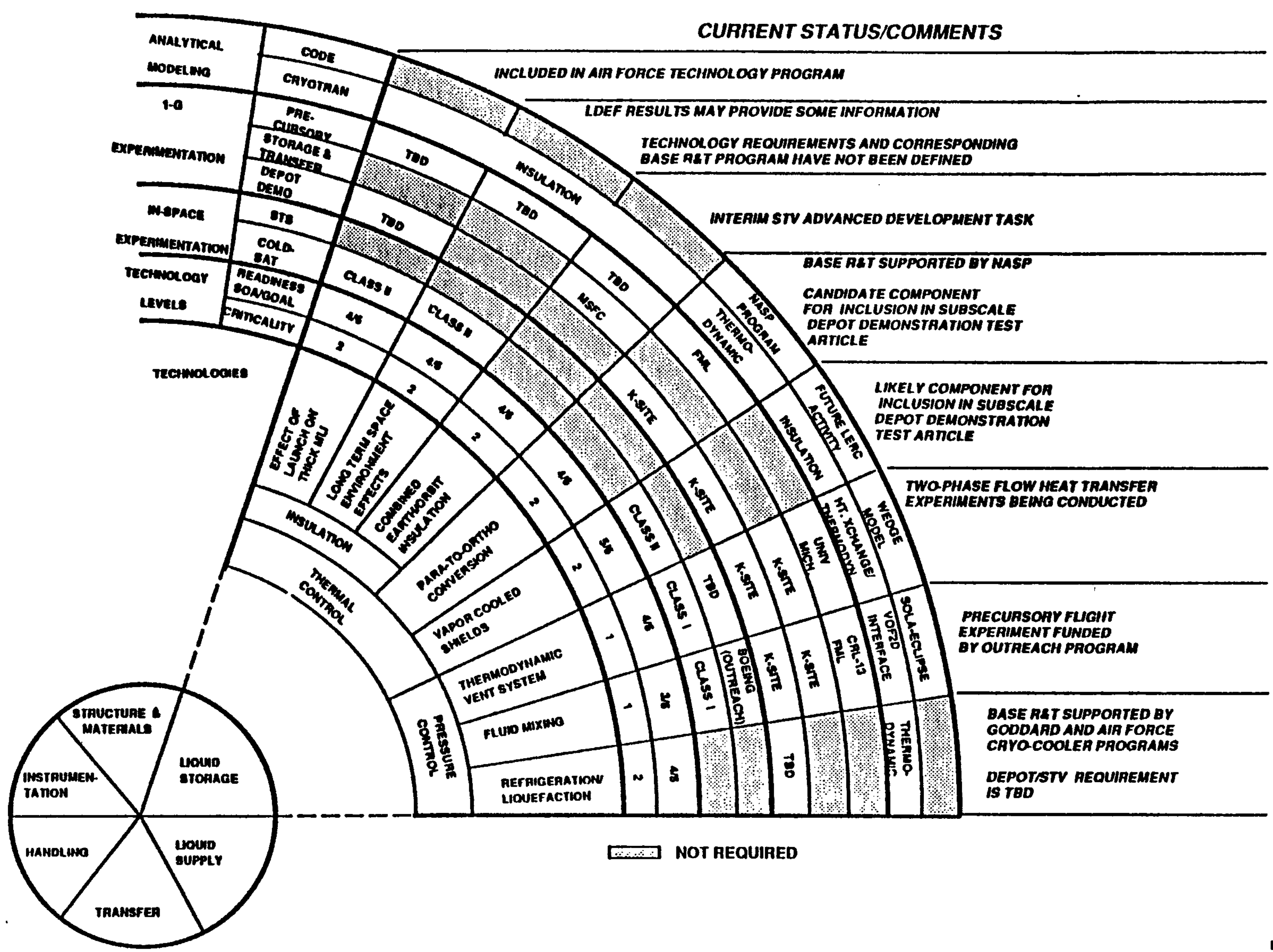
? LEAK DETECTION (IN-SPACE TESTING REQUIREMENT CONCEPT SPECIFIC)

- LIQUID/VAPOR SENSORS
- COMPOSIT (LIGHT WEIGHT) VACUUM JACKET
- LOW THERMAL CONDUCTIVITY COMPONENTS
- LOW PRESSURE TANKAGE
- CONTAMINATION/DEGRADATION OF LIQUID ACQUISITION DEVICE

• LN_2 RESUPPLY $YSTEM DEMONSTRATION (SYSTEM DEMO ADDRESSES SEVERAL TECHNOLOGY NEEDS)

• = IN-SPACE EXPERIMENTATION NEEDED

CRYOGENIC FLUID MANAGEMENT TECHNOLOGY PROGRAM



GENERAL DYNAMICS
Space Systems Division

TECHNOLOGY NEEDS

MISSION CRITICALITY

Technology Category	Interim STV	Space-Based STV	Orbital Depot	Resupply Tanker	Lunar Base	Mars Expedition
• Liquid Storage						
- Thermal Control Systems						
• Degradation of Material		Enhance	Enhance		Enhance	Enable
• Effect of Launch Env. on Thick MLI	Enable	Enable	Enable	Enhance	Enable	Enable
• Combined Foam/MLI Sys.	Enhance			Enhance		
• Para/Ortho Conversion			Enhance		Enhance	Enhance
• Multiple/Coupled VCS			Enhance		Enhance	Enable
- Pressure Control Systems						
• TVS Performance	Enhance	Enhance	Enable	Enhance		Enable
• Fluid Mixing for Stratification Control	Enhance	Enhance	Enable	Enhance		Enable
• Refrigeration/Reliquefaction			Enhance		Enhance	Enable ?
• Liquid Supply						
- Pressurization System Perf.						
• Autogenous	Enhance	Enable	Enable	Enhance	Enable	Enable
• Helium	Enable					
• Mech. (Pumps/Comp.)			Enhance	Enhance	Enhance	Enhance
- Fluid Acquisition						
• Fine Mesh Screen LAD Performance		Enhance ?	Enable	Enable		Enable
• Fluid Settling & Outflow under Low G Conditions	Enhance	Enhance	Enhance	Enhance		Enhance
• Fluid Settling & Outflow under Impulsive Accel.	Enhance	Enhance		Enhance		Enhance
• Impact of Heat Addition on LAD Performance		Enhance	Enhance ?	Enhance		Enhance
• Thermal Subcooling of Liquid Outflow			Enhance	Enhance	Enhance	Enhance

GENERAL DYNAMICS
Space Systems Division

IN-SPACE TESTING OPPORTUNITIES

Technology Category	Critical Data Needed By: Enable	Enhance	Deployment Options: Space Shuttle	ELV	Space Station
• Liquid Storage					
- Thermal Control Systems					
• Degradation of Material	2003?	1997	Deployment /Recovery	Deployment	After 1997
- Pressure Control Systems					
• TVS Performance	1997	1994	Alternate Cryogen	Hydrogen	After 1997
• Fluid Mixing for Stratification Control	1997	1994	Alternate Fluid	Hydrogen	After 1997
• Liquid Supply					
- Pressurization System Perf.					
• Autogenous	1997	1994	Alternate Cryogen	Hydrogen	After 1997
• Helium	1994		Alternate Cryogen	Hydrogen	After 1997
- Fluid Acquisition					
• Fine Mesh Screen LAD Performance	1997		Alternate Fluid	Hydrogen	After 1997
• Fluid Settling & Outflow under Low G		1994	Alternate Fluid		
• Fluid Settling & Outflow under Impulsive Acceleration		1994	Alternate Fluid		
• Liquid Transfer					
- Transfer Line Chilldown	1997		Alternate Cryogen	Hydrogen	After 1997
- Tank Chilldown with Spray	1997		Alternate Cryogen	Hydrogen	After 1997
- No-Vent Fill	1997		Alternate Cryogen	Hydrogen	After 1997
- LAD Fill		1997	Alternate Fluid	Hydrogen	After 1997
- Low G Vented Fill		1997	Alternate Cryogen	Hydrogen	After 1997
• Fluid Handling					
- Liquid Dynamics/Slosh Control		1994	Alternate Fluid		
- Fluid Dumping & Tank Inerting	1997		Alternate Cryogen	Hydrogen	After 1997
• Advanced Instrumentation					
- Quantity Gauging	1997	1994	Alternate Fluid	Hydrogen	After 1997

FLUID PHYSICS THEME ELEMENT

POTENTIAL THRUST:

ENHANCE FUNDAMENTAL UNDERSTANDING OF FLUID BEHAVIOR/DYNAMICS IN REDUCED GRAVITY TO ESTABLISH RELIABLE PREDICTIVE MODELS & DATA BASES FOR ADVANCED SYSTEMS DEVELOPMENT

AND / OR

INITIATE DEFINITION & PRECURSOR FLIGHT EXPTS FOR SPACE STATION FLUID PHYSICS FACILITY (1997 IOC, 1992 CUP)

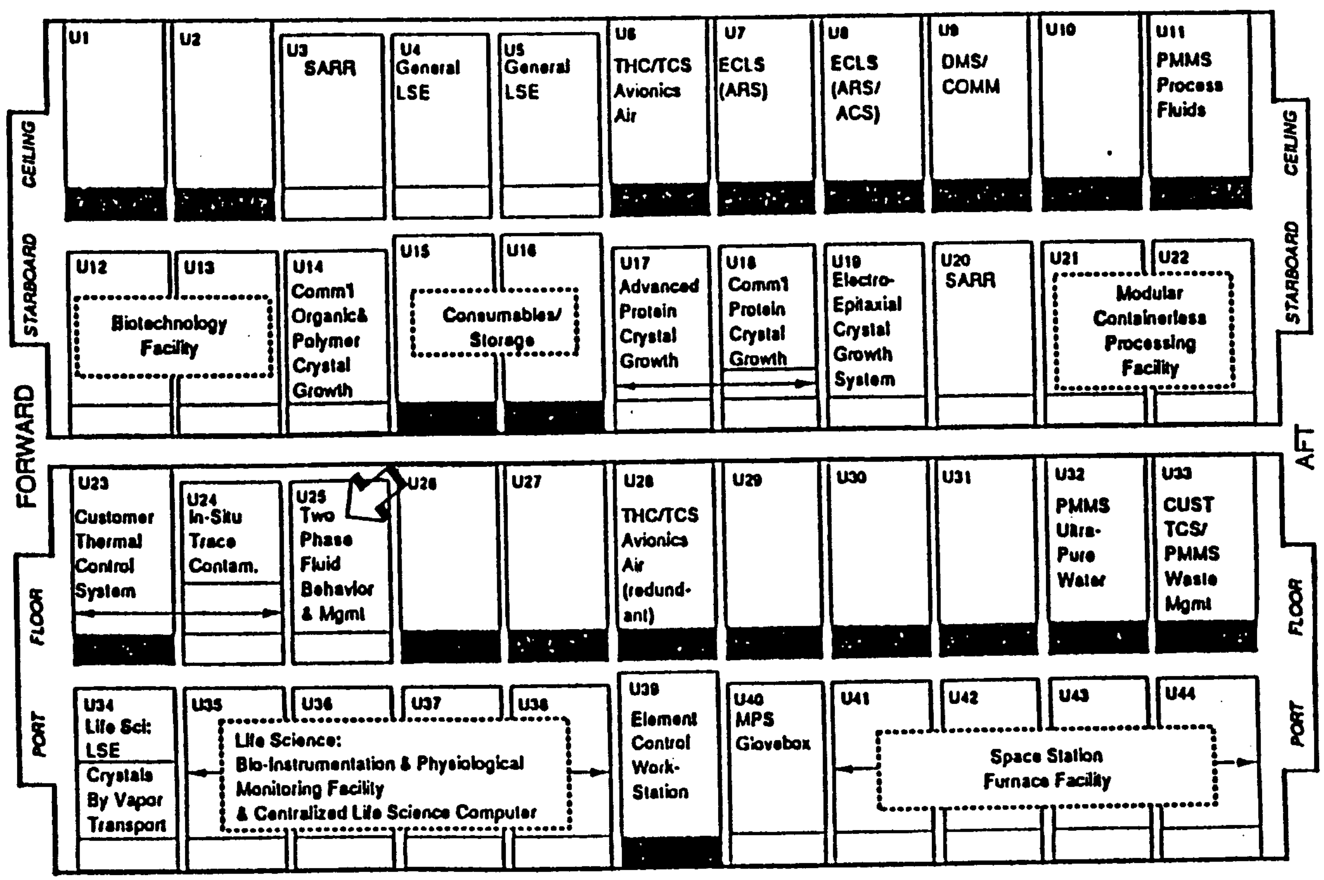
REPRESENTATIVE PROJECTS:

1. ISOTHERMAL MULTIPHASE FLOW
1. LIQUID-VAPOR INTERFACES

2. POOL/FLOW BOILING
2. CONDENSATION / EVAPORATION

3. ADVANCING LIQUID FRONTS
3. BUBBLE / DROPLET DYNAMICS

TYPICALLY:
UNIVERSITY PI
HARDWARE DEVT CONTRACT
FACILITY OPTIONS



SPACE STATION PROGRAM OFFICE Reston, VA	*U.S. LABORATORY MODULE :* *TRIAL PAYLOAD MANIFEST* *PAYLOADS (AUG 1988)*	LAST REVISION DATE: 5/23/88 6/24/88 7/13/88	DRAWN BY CHECKED BY APPROVED	DRAWING NO. 1A SCALE 1" : 5' SHEET 1 OF 1

CRITICAL IN-SPACE TECHNOLOGY NEEDS

- HYDROSTATIC INTERFACE CONFIGURATIONS
  - THE BULK LIQUID LOCATION & CONFIGURATION OF EQUILIBRIUM LIQUID-GAS INTERFACE AS A FUNCTION OF FLUID PROPERTIES, VESSEL GEOMETRY & SIZE, GRAVITY LEVEL, & SYSTEM INITIAL CONDITIONS
- INTERFACE STABILITY & DYNAMICS
  - RESPONSE OF A LOW-G LIQUID-VAPOR INTERFACE TO MECHANICAL & THERMAL DISTURBANCES & ITS EFFECT ON BULK LIQUID MOTION
- BUBBLE DROPLET DYNAMICS
  - THE BUOYANCY AND/OR THERMALLY DRIVEN MOTION OF SINGLE BUBBLE/DROPLET UNDER LOW-G CONDITIONS & INTERACTIONS BETWEEN MULTIPLE BUBBLES/DROPLETS INCLUDING COALESCENCE/BREAKUP
- MULTIPHASE FLOW REGIMES
  - FLOW REGIME PATTERNS & CHARACTERISTICS GENERATED BY FORCED ADIABATIC FLOW OF LIQUID-VAPOR OR IMMISCIBLE LIQUID MIXTURES THRU CONDUITS & FITTINGS AS A FUNCTION OF FLUID PROPERTIES, FLOW RATES, CONDUIT/FITTING GEOMETRY & SIZE, AND GRAVITY LEVEL
- THERMAL/SOLUTAL CONVECTION
  - HEAT & MASS TRANSFER GENERATED BY BUOYANCY DRIVEN FLOWS RESULTING FROM THERMAL &/OR CONCENTRATION GRADIENTS UNDER REDUCED GRAVITY CONDITIONS
- POOL/FLOW BOILING
  - ONSET OF NUCLEATE BOILING & SUBSEQUENT BUBBLE DYNAMICS AS A FUNCTION OF SYSTEM SATURATION, HEAT FLUX, FLUID PROPERTIES, HEATER GEOMETRY, & G-LEVEL FOR BOTH STAGNANT & LIQUID FLOW CONDITIONS
- CONDENSATION/EVAPORATION
  - CONDITIONS FOR CONDENSATION/EVAPORATION OF LIQUID-VAPOR INTERFACES & ITS EFFECTS ON INTERFACE STABILITY/DYNAMICS UNDER LOW-G CONDITIONS FOR BOTH STAGNANT & VAPOR FLOW CONDITIONS
- SOLIDIFICATION/MELTING
  - DYNAMIC BEHAVIOR OF THE SOLID-FLUID FRONT DURING SOLIDIFICATION &/OR MELTING UNDER LOW-G CONDITIONS WITH SPECIAL EMPHASIS ON VOID FORMATION & DYNAMICS DUE TO VOLUME CHANGES
- SHAPE & STABILITY OF LIQUID-VAPOR INTERFACE & THE LOCATION OF THE BULK LIQUID VOLUME IN A TANK IN REDUCED GRAVITY AS FUNCTIONS OF TANK GEOMETRY, FLUID PROPERTIES, TANK SURFACE PROPERTIES, LIQUID FILL LEVEL, AND G-LEVEL
- EFFECTS OF SURFACE TENSION ON LIQUID MOTION IN SPINNING TANKS
- SURFACE PHYSICS FOR SURFACES IN MOTION AT THE SOLID-LIQUID-VAPOR CONTACT LINE IN REDUCED GRAVITY
- HEAT TRANSFER AT THE ONSET OF BOILING IN REDUCED GRAVITY
  - DETERMINE BASIC SHAPE OF THE BOILING CURVE
- DISTRIBUTION OF BUBBLES GENERATED BY DISPERSION DEVICES IN A TURBULENT LIQUID FLOW AT STEADY REDUCED G-LEVEL
- EFFECTS OF GRAVITY ON HEAT TRANSFER FOR FORCED CONVECTIVE BOILING, ESPECIALLY AT TRANSITION TO FILM BOILING AND BURNOUT
- FLUID MECHANICS OF & HEAT TRANSFER TO A THIN LIQUID FILM MOVING ALONG A SOLID SURFACE UNDER THE INFLUENCE OF INTERFACIAL GAS SHEAR, INCLUDING THE STABILITY OF THIN FILMS & THE PROCESS OF DROP FORMATION FROM THE INTERFACE AS A RESULT OF FLOW ACROSS THE LIQUID SURFACE
- PRESSURE DROP & ITS TIME VARIATION FOR TWO-PHASE SLUG FLOW IN REDUCED GRAVITY FOR STEADY FLOW CONDITIONS OR DURING VARIATIONS IN FLOW RATE & VARYING G-LEVELS
- SHAPE & RATE OF ADVANCE OF A LIQUID FRONT MOVING ALONG A SOLID SURFACE WHICH IS BEING THERMALLY QUENCHED IN REDUCED GRAVITY

NASA Lewis Research Center

SPACE EXPERIMENTS DIVISION
In-Space Technology Experiments
Fluid Physics Subtheme

SFSD
Space Flight Systems Directorate

GENERAL PLANNING MODEL

FLUID MANAGEMENT NEED ? | GRAVITY EFFECTS ? | MATURITY OF UNDERSTANDING ?

MISSION DRIVERS	ADVANCED SYSTEMS	TECHNOLOGY ELEMENT	FLUID PROCESSES/ PHENOMENA CATEGORIES	REFERENCE EXPERIMENT SETS
Growth Space Station	Dynamic Power	Thermal Energy Storage	Interface/Capillary Phenomena	Hydrostatic Interface Configurations
Space Based Transportation	Chemical Energy	Condensers	Multiphase Flow	Interface Stability and Dynamics
Lunar Outpost /Base	Nuclear Power	Boilers	Multicomponent/ Coupled Transport	Bubble/Droplet Dynamics
Spacecraft	Life Support	Phase Separators	Phase Change Processes	Multiphase Flow Regimes
	OTV	Fluid Storage/Supply		Thermal/Solutal Convection
	Cryo-Depot	Radiators		Pool/Flow Boiling
	Spacecraft Systems	Thermal Loops		Condensation/ Evaporation
	Space/Lunar Based Processing	Materials Processing		Solidification/ Melting
	Instrumentation Cooling			

Fluid Mngmnt. Propulsion	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP December 6-9, 1988	Fluid Physics

EXAMPLE: OTV

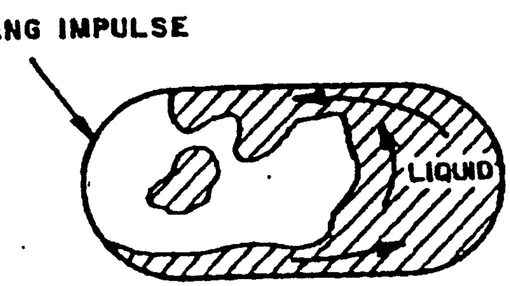
Fluid Process: Interface configuration and stability

Problems:
- gas-free liquid transfer
- quantity-gaging – liquid location is unknown so elaborate, heavy, complex, and limited accuracy systems are used.

Technology Need: Accurate prediction of interface location so a simple, reliable, accurate gaging system can be used.

Fluid Process: Interface dynamics and bulk liquid motion.

Problem: Docking causes large impulsive accelerations. The liquid undergoes gross motions which degrade control and increase liquid transfer time.



Technology Need: Validate method (CFD code) to predict large free-surface motions in low-g and the duration of such motions

PROPULSION THEME ELEMENT

POTENTIAL THRUST:

DEFINITION & ENGINEERING DEVELOPMENT OF PROPULSION FLIGHT PROJECTS,

- MAY BE BEYOND OUTREACH SCOPE DUE TO COST, CARRIER COMPLEXITY, MULTI-AGENCY SPONSORSHIP

REPRESENTATIVE PROJECTS:

1. PLUME CHARACTERISTICS & IMPACT
2. ELECTRIC PROPLUSION SPACE TEST
3. MAN TENDED, MULTIDISCIPLINE SPACE TESTBED

RECOMMENDATION PROCESS FINDINGS

TOPIC	NUMBER OF RECOMMEN.	AVERAGE SCORE (1 TOP PRTY)	CONSENSUS PRIORITY
PLUME IMPACTS & CHARACTERISTICS	10	1.2	X
ELECTRIC PROPULSION SPACE TEST	9	1.9	X
MULTIDISCIPLINE SPACE TEST BED	7	2.4	X
LARGE NOZZLE (5-25K LB.) SPACE EVALS	1	1	
FAULT DIAGNOSTICS & MAINTENANCE	1	1	
ENVIRONMENTAL PROTECTION	1	2	
IN-SPACE ENGINE RESTARTS	1	6	
VACUUM WELDING	1	7	
IN-SITU PROPELLANTS	1	8	

PROGRAMMATIC CONCERNS

SCOPE

- DOLLAR LIMITS/GUIDELINES
- TIME CONSTRAINTS/FLEXIBILITY WITH DISCIPLINE & INSTITUTION
- TECHNOLOGY READINESS LEVELS (SYSTEM DEMOS?)
- FROM DEFINITION THROUGH DEVELOPMENT?
- FACILITY CONCEPT WITH MULTIPLE INVESTIGATORS

SELECT CRITERIA

- "SPREADING DOLLARS ACROSS THEMES"?
- PROJECTS WHICH SPAN SUBTHEMES
- HIGH DOLLARS ON ONE ACTIVITY PRECLUDES OTHERS?

COMMITMENT

- UNIVERSITY INVOLVEMENT